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DIGITAL VIDEO TRANSMISSION FROM THE P-3C TO BEYOND LINE-OF-SIGHT DESTINATIONS

by

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The goal of this thesis is to provide a feasibility analysis concerning the transmission of real-time, full motion digital video from a P-3C maritime surveillance aircraft to both line of sight and beyond line of sight (BLOS) destinations. The ability to receive live video on the ground or onboard ship will aid the warfighter in making more timely and correct tactical decisions due to increased intelligence capabilities. Currently, the capability exists to transmit still frame images over a UHF satellite link to shore installations using specially modified P-3C aircraft. Full motion video can also be transmitted using a hybrid system borrowed from the Pioneer UAV program; however, it is limited to line of sight transmission only. Both of these current capabilities utilize an analog format and analog video quality resolution.

The U.S. Navy has a standing Mission Need Statement for airborne Command, Control, Communications, and Intelligence (C^3I). More specifically, there exists a need for improved electro-optical capabilities as well as rapid exchange of command, surveillance, and targeting data with both ships at sea and shore installations. This thesis traces the flow of data from the video source to the ultimate destinations and identifies possible solutions for the design of the transmission link. The fundamental technologies exist now to provide digital full motion video from an aircraft via a high capacity satellite data link. To ensure capatability with other DOD communication systems, compliance with Common Data Link (CDL) was incorporated in the proposed system. This thesis proves the proposed video transmission system is technically feasible.

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ACRONYMS

ACTS	Advanced Communications Technology Satellite
ADVS	Adaptive Digital Video Standard
AIP	ASUW Improvement Program
AM	Amplitude Modulation
AOR	Area of Responsibility
ASD/C^3I	Assistant Secretary of Defense/C^3I
ASUW	Anti-surface Warfare
ASW	Anti-submarine Warfare
ATARS	Advanced Tactical Airborne Reconnaissance System
BER	Bit Error Rate
BFN	Beam Forming Network
BGPHES	Battle Group Passive Horizon Extension System
BLOS	Beyond Line of Sight
BPSK	Binary Phase Shift Keying
BTR	Bit Timing Recovery
CCD	Charged Coupled Device
CCOI	Critical Contact of Interest
CDL	Common Data Link
CDMA	Code Division Multiple Access
CHBDL	Common High Bandwidth Data Link
CL	Command Link
COI	Contact of Interest
COMSAT	Communication Satellite Corporation
CR	Carrier Recovery

CTF	Task Force Commander
CTG	Task Group Commander
CVSD	Continuous Variable Slope Delta Modulation
C^3I	Command, Control, Communications & Intelligence
DAMA	Demand Assigned Multiple Access
DCS/DCIU	Digital Camera System/Digital Camera Interface Unit
DCT	Discrete Cosine Transform
DFT	Discrete Fourier Transform
DOD	Department of Defense
DPS	Digital Product Server
DSCS	Defense Satellite Communications System
DSPO	Defense Support Projects Office
DS-SS	Direct Sequence-Spread Spectrum
EHF	Extremely High Frequency
EIRP	Effective Isotropic Radiated Power
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FINDS	Flexible Information Dissemination System
FM	Frequency Modulation
FSS	Fixed Satellite Service
GDA	Gimballed Dish Antenna
GPS	Global Positioning System
G/T	Gain-to-Noise Temperature Ratio
HPA	High Power Antenna
IAM	Imagery Acquisition Module
ICS	Imagery Communication Services

ICT	Image Composition Tool
IES	Image Exploitation Service
IM	Intermodulation
IMGR	Image Manager
INTELSAT	International Telecommunications Satellite Consortium
IPS	Imagery Print Services
IRDS	Infrared Detection System
ISAR	Inverse Synthetic Aperature Radar
ITU	International Telecommunications Union
IVWR	Image Viewer
I & W	Indications and Warning
JDISS	Joint Deployable Intelligence Support System
JMCIS	Joint Maritime Command Information System
JPL	Jet Propulsion Lab
JSIPS	Joint Services Image Processing System
JTF	Joint Task Force
LDR	Low Data Rate
LEASAT	Leased Satellite
LNA	Low Noise Amplifier
LOS	Line of Sight
MBA	Multi-beam Antenna
MDR	Medium Data Rate
MPA	Maritime Patrol Aircraft
MILSATCOM	Military Satellite Communications
MIST	Modular Interoperable Surface Terminal
MMIC	Monolithic Microwave Integrated Circuits

NAVAIR	Naval Air Systems Command
NAVCOM	Navigator/Communicator
NAWC	Naval Air Warfare Center
NITF	National Imagery Transmission Format
NRZ	Non-Return to Zero
NTSC	National Television Systems Committee
OTCIXS	Officer in Tactical Command Information Exchange System
OTH-T	Over-the-Horizon Targeting
PANAMSAT	Pan American Satellite
PCE	Platform Communications Element
PM	Phase Modulation
PN	Psuedonoise
PSD	Power Spectral Density
PSK	Phase Shift Keying
QPSK	Quadrature-Phase Shift Keying
RL	Return Link
RTVD	Realtime Video Downlink
SCE	Surface Communications Element
SHF	Super High Frequency
SIGINT	Signal Intelligence
SLR	Single Lens Reflex
TACCO	Tactical Coordinator
TDMA	Time Division Multiple Access
TOSS	Tactical Optical Surveillance System
T/R	Transmit and Receive
TSC	Tactical Support Center

TWT	Traveling-wave Tube
UAV	Unmanned Aerial Vehicle
UW	Unique Word

I. INTRODUCTION AND BACKGROUND

A. INTRODUCTION

The goal of this thesis is to provide a feasibility analysis concerning the transmission of real-time, full motion digital video from a P-3C maritime surveillance aircraft to both line of sight and beyond line of sight (BLOS) destinations. The ability to receive live video on the ground or onboard ship will aid the warfighter in making more timely and correct tactical decisions due to increased intelligence capabilities. Currently, the capability exists to transmit still frames via satellite link, or full motion video by line of sight only, via specially modified P-3C aircraft. Both of these current capabities utilize an analog format and analog video quality resolution.

The U.S. Navy has a standing Mission Need Statement for airborne Command, Control, Communications, and Intelligence (C^3I) for Maritime Patrol Aircraft (MPA). More specifically, there exists a need for improved electro-optical capabilities and rapid receipt and exchange of command, surveillance, and targeting data. The fundamental technologies exist now to provide digital full motion video via a satellite link to ground stations. This thesis will address incorporating onstation MPA as an intelligence gathering platform, thereby becoming a primary source of this video. It is essential that this proposed system meet compatability considerations to ensure rapid dissemination of images to fleet commanders or other time critical users.

B. BACKGROUND

In 1981, the Tactical Optical Surveillance System (TOSS) program was initiated. This program called for four P-3 aircraft to be configured in what essentially was an advanced long range electro-optical imaging system to be used for the collection of high resolution airborne intelligence imagery. The optics consist of a stabilized gimbaled mirror in conjunction with a cassegrain high performance multi-spectral telescope of variable focal length. Multiple sensors such as charged coupled devices (CCDs) and still frame digital cameras were integrated into the surveillance system. The system is capable of providing imagery on video tape, photographic film, and via a data link as a still frame image. The TOSS system has evolved into the Cluster Ranger surveillance system with improved electro-optical surveillance capabilities. Both of these systems were developed at the Naval Air Warfare Center (NAWC), with the Cluster Ranger system currently scheduled to be installed in all active duty P-3s as part of the ASUW Improvement Program (AIP). This system currently has the capability of transmission of still frame imagery over a UHF SATCOM data link.

In addition to the Cluster Ranger, there are other electro-optical imagery systems that can be used from maritime patrol aircraft. The P-3 Real-Time Reconnaissance System is a carry-on system that has the capability for real time transmission of both color and black and white video imagery in full motion. The system uses a Pioneer UAV data link and transmits imagery via line-of-sight to a Pioneer ground receiving station over C-band. The video imagery can be acquired from any onboard source that has the RS-170 monochrome or NTSC color composite format such as TOSS or available infrared sensors. This system is available for fleet use, however, it is unencrypted and requires a mobile ground station to accompany the aircraft due to its line-of-sight limitation.

As of now, only still frame grabs from analog video are available for beyond line of sight transmission. These images consist of digitized frames of analog video consisting of 640x480 pixels. The still frame images are encrypted and downlinked utilizing UHF line of sight or UHF SATCOM relays. Although currently in place, this system does not permit high resolution imagery, which limits intelligence capability. In addition to the lack of high resolution, it has a relatively slow transmission rate, taking up to 10 minutes to receive a still image. The ability to receive motion video either at full motion (30 frames/sec) or at a stop-motion (lesser rate) will greatly aid the interpreter's ability to effectively analyze the imagery.

The development of a full motion video transmission capability for P-3s is currently being investigated. Much of the technology is being developed by programs such as the Unmanned Aerial Vehicles (UAV) and other commercial applications such as direct broadcast digital television. Technical difficulties arise when considering a system capable of transmitting the extremely large bandwidths associated with full motion video. Areas of concern include the required antenna system, availability of satellite transponders, and incorporating existing video compression technologies, while maintaining compliance to existing protocols. This thesis addresses these challenges by following the flow of information (image data) from the intelligence gathering source to its ultimate destination, examining in depth the aforementioned areas of concern.

II. CONCEPT OF OPERATIONS

A. MULTIMISSION CAPABILITIES/ENHANCEMENT

1. General Description

Maritime patrol forces possess multimission capabilities that allow them independently to accomplish rapid comprehensive surface surveillance, enable broad ocean surface ship interdiction, provide Indications and Warning (I&W), conduct ASUW strikes, and effectively counter modern nuclear and diesel submarines with early and sustained deep water or shallow water littoral ASW. In addition, patrol aircraft provide C^3I connectivity for battlegroups across warfare areas, serve as accurate over-the-horizon targeting (OTH-T) platforms working in concert with CVBG, SAG, and SSN ASUW assets, and integrate fully with other battlegroup ASW assets for effective coordinated ASW sanitization [Ref. 1].

These longstanding multimission capabilities are delivered by a common multipurpose aircraft and aircrew. Differing mission systems are integrated within the aircraft and do not interfere with each other. The addition of a system capable of transmitting video not only enhances the current multimission capabilities, but also it provides the fleet with an asset that can perform a new array of tasks.

2. Maritime Surveillance

Maritime surveillance is a fundamental requirement of Naval warfare, and long range open ocean and littoral surveillance is the traditional mission of maritime patrol aircraft (MPA). In the Pacific campaigns of World War II, the Korean Conflict, the Cuban Missile Crisis, the Vietnam War, and in Operation Earnest Will during the Iran-Iraq War, the overwhelming dominant employment of MPA has been in the execution of patrol aviation's primary surveillance mission. In the Maritime Interdiction Force operations during Operation Desert Shield, over 6500 vessels were queried by P-3 aircraft, and all critical contacts of interest (CCOI) entering the area were initially identified by MPA [Ref. 1].

Under command of a Task Force Commander (CTF), VP squadrons routinely perform independent maritime surveillance flights within their Task Group Commander's (CTG) area of responsibility (AOR). These missions involve searching, locating, and photographing specified contacts of interest. Upon completion of the mission, the corresponding photographs are developed and analyzed time-late at the CTG's Tactical Support Center (TSC). This inherent delay affects the tasking of subsequent surveillance flights. With a video transmission system, onstation P-3s would have the capability to send real-time imagery to the TSC for analysis, increasing the effectiveness of future tasking for follow on events. Also, if the data link was full-duplex, onstation P-3s could receive updated tasking through imagery.

The increased capabilities provided by a video transmission system would also enhance the use of MPA in our comprehensive counter-narcotics strategy. Equipped onstation aircraft would be able to provide the Joint Task Force (JTF) Commander with real-time images of CCOIs enabling immediate response with the appropriate actions.

3. Anti-Surface Warfare

MPA forces also possess a robust capability in both independent and coordinated Anti-Surface Warfare (ASUW). From forward deployed sites, P-3s become an early onscene asset with an extensive onstation duration, providing effective high search rate surveillance. This, coupled with employment of the Harpoon, an accurate stand-off anti-ship weapon, make the P-3 a potent self-contained area ASUW platform [Ref. 1].

A recent modification that improved communication and the ability to update tasking is the Outlaw Hunter suite. Outlaw Hunter consists of an officer in tactical command information exchange system (OTCIXS) tactical data processor with a Global Positioning System (GPS) interfaced with the inverse synthetic aperture radar (ISAR) system. This proven low cost C^3I suite provides extremely accurate target positioning in real time to all ASUW capable ships and submarines on the net [Ref. 2]. The third generation of this OTH-T/C^3I suite is OASIS III, which is at the heart of the ASUW Improvement Program (AIP).

OASIS III deletes the need for its usual workstation by integration into the Tactical Coordinator (TACCO), Navigator/Communicator (NAVCOM) and operator stations. Information is displayed through new color high resolution 19 inch screens with programmable entry panels, trackballs and standard electro-mechanical keyboards. These new universal displays and controls accept and display non-acoustic information (IRDS, ESM, Radar) using a switching interface for connecting OASIS III OTH-T data at each of the workstations [Ref. 3].

The communications upgrade provides for all the tactical networks (OTCIXS, TADIXS-B, TRAP and dual receive TRE Links) to transmit and receive targeting information without interfacing with HF, UHF and VHF radios. This C^3I capability is further enhanced by the modification of the current wideband SATCOM data and voice system to a narrow band ATCOM Demand Assigned Multiple Access (DAMA) unit [Ref. 3].

A new addition in a roll-on, roll-off package, Cluster Ranger is a standoff stabilized long range electro-optical (E/O) surveillance system utilized for the collection of airborne high resolution intelligence imagery [Ref. 3]. The attributes of the Cluster Ranger system will be further discussed in Chapter III. With a video transmission system onboard, onstation P-3s could transmit real-time electro-optical imagery gathered from Cluster Ranger and transmit it over the horizon to the TSC, or line-of-sight to command ships within range. Once the images reach the TSC, then they could be entered into the Joint

Maritime Command Information System (JMCIS) allowing for rapid, effective dissemination of imagery to other JMCIS users across strategic, theater, and tactical lines.

B. OPERATIONAL SYSTEM EMPLOYMENT (U)

Due to its classified content, the remainder of this chapter can be found in the Appendix.

III. SENSORS

A. CLUSTER RANGER

1. System Description

The Cluster Ranger system is a derivative of the proven Tactical Optical Surveillance System (TOSS), that was developed during the 1980s. The Cluster Ranger is an electro-optical imaging system that has the capability of high resolution airborne imagery both in video format and on film simultaneously. The video format can be transferred to video tape or transmitted as a still frame image via data link over UHF radio. This format can be adapted to data links for beyond line-of-sight transmission. The system is currently configured for installation on P-3 aircraft, and systems are currently in use.

The Cluster Ranger consists of two major equipment areas, the Optical Station and the Auxiliary Station. The Optical Station is the primary equipment rack that supports the optics and the associated sensors. This is currently configured for placement at the port side forward observer's station on the P-3 aircraft. The weight of this station is approximately 350 lbs. The Auxiliary Station houses the system electronics and controls and is located next to the Optical Station. The Auxiliary Station weighs 300 lbs for a total system weight of 650 lbs [Ref. 4:p. 2]. This will not greatly affect aircraft weight and performance considerations during typical mission profiles.

2. System Characteristics and Capabilities

In addition to the two major equipment areas, there exists a flight station acquisition sight. This relatively wide-view sight allows the pilot to acquire the target of interest and hand it off to the Cluster Ranger operator who has a relatively narrow field of view. The acquisition sight interacts with the servo electronics unit to position the optics for more efficient tracking.

The optical station houses the stabilization system, the optical train, and all the system sensors. These systems are isolated from aircraft vibration through the use of pneumatic vibration dampers. The system employs a gyro-stabilized seven inch mirror that is located directly behind an optical quality window (see Figure 3.1). The mirror is driven by a servo electronics unit, and is controlled via a thumb-controlled joystick. An optional automatic video tracker is available that allows the operator to lock onto a target without manual tracking. A large angular travel is available: 30 degrees up and 50 degrees down in elevation travel, and 45 degrees both forward and aft in azimuthal angular travel.

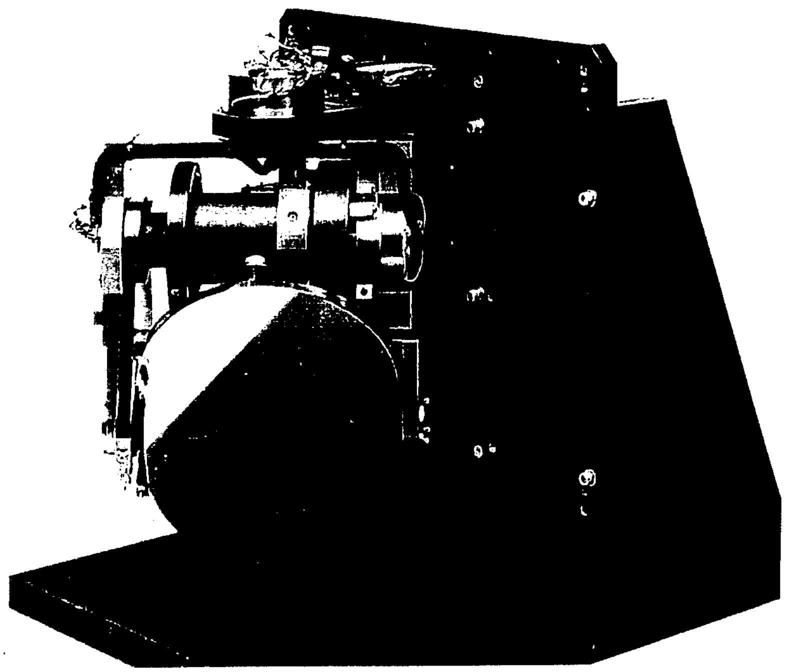


Figure 3.1: Gyro-stabilized Mirror [Ref. 4]

The primary component of the optical train is a Cassegranian telescope with a seven-inch aperture. This telescope has a variable focal length controlled by an electronic turret that contains auxiliary lenses. This enables the operator to choose between 40, 70, or 120-inch effective focal length. An optical beam splitter is used to separate the near infrared imagery, which occurs in the 0.6-1.1 μm wavelength range, from that of the visible spectrum, which occurs at the wavelength range of 0.4-0.6 μm. The near infrared imagery is projected onto a Charged-Coupled Device (CCD) (see Figure 3.2).

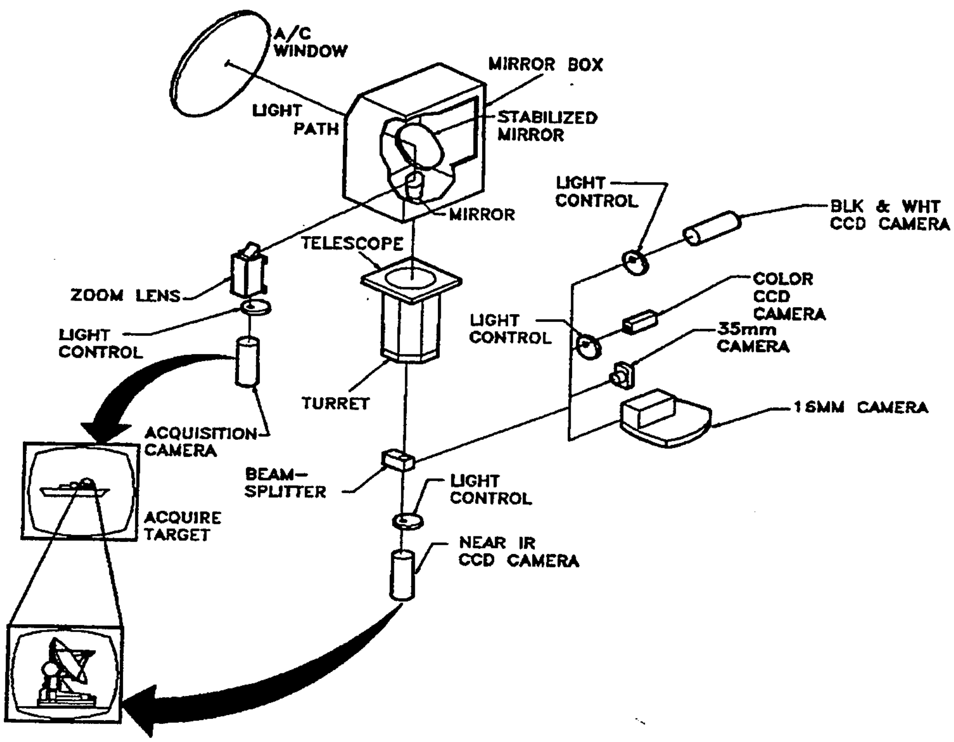


Figure 3.2: Cluster Ranger Optical Train [Ref. 4]

The Infrared Detection System (IRDS) can also be integrated into this system for use in night-time surveillance. The IRDS is installed in all active duty P-3s and is an infrared camera system mounted on a rotating turret beneath the aircraft. This turret is capable of 360 degrees of rotation and elevation travel down to vertical. The system is controlled by the nonacoustic operator via a joystick with video output at the station, with the capability of recording to videotape. The Tactical Coordinator (TACCO) has a repeating video monitor at his station for tactical evaluation.

The main beam of the optical train is routed to the primary surveillance sensors. These sensors include a visible spectrum black and white CCD camera, a color CCD camera, a 35mm still Single Lens Reflex (SLR) camera, and a 16mm high speed motion picture camera (see Figure 3.2). The system as described is proven operationally and has been flying for several years. The surveillance sensors can be modified with the addition of a high resolution digital camera (Pulnix TM1001) that can produce images with resolutions on the order of 1024*1024 pixels for increased intelligence capabilities.

The Cluster Ranger system is currently scheduled to be installed in all active duty P-3Cs in accordance with the P-3C ASUW Improvement Program (AIP). The Pulnix TM1001 digital camera would be a resolution improvement option and is currently commercially available.

3. System Output

A goal of the Cluster Ranger imagery system is to have the ability for an operator to select the information to be transmitted. For full motion imagery the system output is high quality black and white or color analog images in the National Television Systems Committee (NTSC) format. The NTSC format divides an image into 525 horizontal scanning lines. The number of scanning lines determines the vertical detail, or the resolution, of the picture. Resolution is expressed in terms of the maximum number of lines alternating between black and white (or color) that can be resolved in the image along the pertinent direction by a human observer. In intelligence and information gathering missions, the resolution will be of great importance. When discussing image resolution, the term aspect ratio refers to the ratio of width-to-height. This aspect ratio for NTSC format is typically 4:3. Therefore, an image that is divided into 525 vertical elements would have approximately 700 horizontal elements. The practical limits of resolution in this format are lower due to limitations of transmission.

When transmitting images of moving objects, a video transmissin system must deal with four basic factors:

1. There must be a perception of the distribution of brightness, or light.
2. There needs to be a perception of depth to enable a perspective of three-dimensions.
3. There must be a perception of motion relating to the first two factors.
4. (Optional) There should be a perception of color.

Monochrome transmission standards meet the first three considerations while color video transmission standards include all four. A video transmission system must convert these three or four factors into electical equivalents prior to modulation and transmission.

The NTSC video standard calls for the transmission of a full 30 frames per second. By flashing 30 still pictures per second on the display tube of the receiver the human eye perceives them to be moving pictures. This effect is due to a phenomenon known as persistence of vision. Full motion video at this rate is the goal, however, due to bandwidth limitations that will be discussed in following chapters, this may not be available. The alternative would be to transmit series of still frames at a rate at which the user can get a sense of motion of the target of interest.

In addition to the number of frames per second, the resolution is also limited by the available bandwidth in which to transmit. The greater the bandwidth, the better the images will appear. The increased bandwidth will come at a price, particularly regarding airborne platforms that have size and power limitations. This bandwidth restriction will become a constraint, forcing possible tradeoffs. Because the video image quality is so closely related to the available bandwidth, a brief explaination of the relationship is required.

For computing bandwidth requirements, we will define R_v as the image resolution in the vertical direction, and R_h as the horizontal image resolution. The scanning process that changes an image into a video signal in the camera (at the transmitter) and then reconstructs the image on the display (at the receiver) requires time for the electron beam to retrace and start a new rasterscan at the top of the image (see Figure 3.3). A rasterscan is essentially the process of taking a horizontal strip across the image on which discrete square elements called pels or pixels (picture elements) are scanned from left to right. When the right-hand end is reached, another lower, horizontal strip is explored, and so on until the whole image has been scanned [Ref. 5:p. 867]. Consequently, we find that the

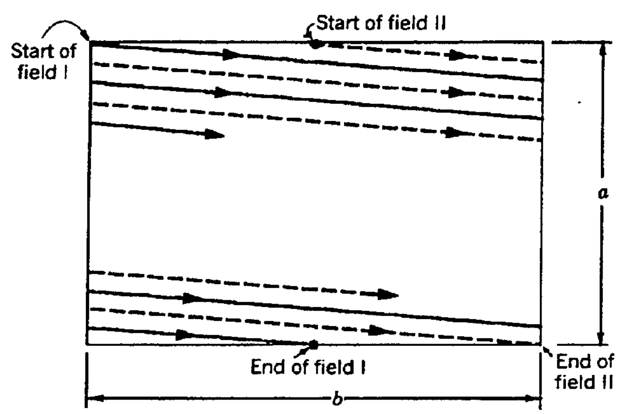


Figure 3.3: Analog Video Raster Scan [Ref. 6]

vertical resolution in a video picture is reduced due to the time it takes the beam to retrace to the top of the screen, which is called vertical retrace. The vertical resolution is described by:

$$R_v=k(N-2N_{vr}),$$

where N is the total number of raster scan lines, and N_{vr} is the number of lines per field that are lost during vertical retrace. The k factor, called the Kell factor, is typically between 0.6 and 0.7, and is the result of avoiding aliasing. Aliasing refers to a high-frequency component in the spectrum of the message signal apparently taking on the identity of a lower frequency in the spectrum of a sampled version of the signal [Ref. 6:p. 181].

To determine R_h, we assume that the picture elements (pixels) are arranged as alternate black and white squares along the scanning line. The corresponding video signal is a square wave with its fundamental frequency equal to the video bandwidth. Since there are two pixels per cycle of a square wave, the horizontal resolution may be expressed as:

$$R_h=2B(T-T_{hr}),$$

where B is the video bandwidth, T is equal to the total duraton of one scanning line, and T_{hr} is the duration of a horizontal retrace. We try to make vertical and horizontal resolutions equal, so that:

$$\frac{R_v}{\text{Height}}=\frac{R_h}{\text{Width}}.$$

Using these relationships, and solving for bandwidth B, we get the relationship:

$$B=\frac{k}{2}\left(\frac{\text{Height}}{\text{Width}}\right)\left(\frac{N-2N_{vr}}{T-T_{hr}}\right).$$

For NTSC systems:

Aspect ratio=	4/3
Total lines per frame (N)=	525
Vertical Retrace (Nvr)=	21 lines/field
Kell factor (k)=	0.7
Total line time (T)=	63.5 µs
Horizontal retrace time (Thr)=	10 µs

Substituting, we compute bandwidth B=4.2 Mhz, which is the actual maximum frequency in the standard video signal.

This analog video information must be digitized prior to transmission by a video digitizer. Within this video digitizer, the resolution, frame rate, brightness levels, and color depth can be adjusted to meet constraints as necessary. To illustrate an the amount of information a digital data link may have to transmit, we will assume a capability of 256 levels of brightness. Because the NTSC video standard requires an analog bandwidth of 4.2 Mhz, the video signal must be sampled at a Nyquist rate of at least 8.4 Mhz. To obtain 256 levels of brightness, 8 bits per sample are required. This will equate to a data rate of approximately 67.2 Mbps before compression. For color NTSC video, 3 color pixels are required for each black and white pixel, for a generated data rate of approximately 201.6 Mbps. The digital camera option will generate relatively large amounts of information due to its high resolution (1024 x 1024) and number of brightness levels. This is equivalent to approximately 8.4 Mb per image. The number of frames of digital imagery per second will dictate the outgoing data rate from the sensor prior to compression.

B. ALTERNATE IMAGERY SOURCES

There are several sources of RS-170 or NTSC video available for beyond line-of-sight transmission. These range from hand-held minicam cameras to the installed IRDS. There are of course, advantages and disadvantages to each of these systems, and only a few of the systems will be discussed here. New, large scale optical systems similar to the Cluster Ranger will not be considered under the assumptions that the AIP program will proceed and that the Cluster Ranger, or a scaled down version of it, will be installed. With these assumptions, only a low cost alternative is practical.

The IRDS currently installed in all active-duty P-3C aircraft would be a low cost alternative to provide imagery but only in the infrared spectrum. Capable of an azimuthal 360 degrees of look down capability, the IRDS system has been operationally proven and enables excellent night-time surveillance capabilities. Video output from the IRDS processor would be routed to the transmission equipment for data link transmission. The relatively low cost of conversion would be offset by a reduced surveillance and intelligence gathering capability. The IRDS is limited in zoom capability and is affected by atmospheric conditions such as water vapor.

Another low cost alternative to the Cluster Ranger would be a hand-held/mounted minicam capable of analog or digital color/black andwhite imagery in the visible spectrum. The minicam would have a zoom capability of approximately 8:1. This may be mounted behind a previously installed optical window located on the port side of the flight station on a vibration-dampening mounting. All tracking and controlling would be done manually at the camera itself. This proposed imagery source, along with IRDS, should be considered only in event of cancellation of the AIP program or the removal of the Cluster Ranger system from the program, due to the vastly superior intelligence-gathering capabilities of the Cluster Ranger system.

IV. DATA PROCESSING AND POWER REQUIREMENTS

A. COMMON DATA LINK (CDL)

1. What is CDL?

Due to the increasing number of imagery and signals intelligence systems within the Department of Defense which use or require a high-capacity, secure, jam-resistant data link to connect the airborne sensor payloads to the land or shipboard control and processing segments, a Common Data Link (CDL) program was established. Common interfaces between these multi-service and -agency systems are essential for interoperability, and they provide the opportunity for significant cost savings in development, procurement and support of airborne and ground systems. In 1988 the CDL program policy was mandated by Congress and requires that CDL A-level specifications be used in all Service and Defense Agency imagery and signals intelligence collection systems unless an exception is granted by the Assistant Secretary of Defense/Command, Control, Communications, and Intelligence (ASD/C^3I) [Ref. 7].

The CDL Segment, consisting of the Platform Communications Element (PCE) and the Surface Communications Element (SCE), provides full duplex communication between airborne platform user equipment and surface user equipment. In general, the two subsystems have inverse data processing functions. For example, the airborne subsystem multiplexes, encodes, interleaves, modulates and upconverts downlink data and transmits it to the surface terminal which receives, downconverts, demodulates, deinterleaves, decodes and demultiplexes the data. The two aggregate time division multiple access (TDMA) channels of the subsystem are designated as the Command Link, CL (uplink) and Return Link, RL (downlink) [Ref. 8:p. 31]. The CL and RL operate at the data rates summarized in Table 4.1. In order to comply with CDL, a PCE must possess the appropriate CDL common module hardware and have the ability to transmit/receive the specific CDL waveform.

CDL Data Rates

Command Link (CL)	Return Link (RL)		
600 bps	16 Kbps	24 Kbps	32 Kbps
1200 bps	40 Kbps	48 Kbps	56 Kbps
2400 bps	64 Kbps	72 Kbps	80 Kbps
4800 bps	96 Kbps	112 Kbps	120 Kbps
2 Mbps	128 Kbps	144 Kbps	168 Kbps
	192 Kbps	386 Kbps	512 Kbps
	768 Kbps	772 Kbps	1.024 Mbps
	1.536 Mbps	1.544 Mbps **T1**	2.048 Mbps
	3.088 Mbps **2T1**	3.152 Mbps **T1C**	6.312 Mbps **T2**
	6.176 Mbps	10.710 Mbps	137.088 Mbps
	274.176 Mbps		

Table 4.1 [Ref. 8:p. 43]

Presently, CDL is utilized in two frequency spectra: X-band (7.25 - 8.4 Ghz) and Ku-band (11.7 - 14.5 Ghz). Table 4.2 shows the interoperability of the CDL compliant surface and airborne terminals and their respective frequency spectrums. Of specific interest is the surface CHBDL (Common High Bandwidth Data Link) terminal, which is to be installed onboard all US Navy aircraft carriers in the near future. As a CDL compliant platform, the P-3C would then be able to transmit imagery via the CDL waveform directly to the CHBDL capable ships.

The remainder of this section will address TDMA, which is the technique CDL uses to access satellite transponders, and the different modulation techniques utilized by CDL. The rest of this chapter will address data compression, which is crucial because of the inherently large bandwidths associated with full-motion video, and power amplification.

KEY:

√ Fully interoperable
May require mission specific data files

NOTE: All data links are 10.71, 137 & 274 Mb/s capable unless otherwise noted

SURFACE TERMINALS		AIRBORNE SYSTEMS: Army		Air Force				Navy		Joint Services		
SUPPORTED PROGRAM		Guardrail/Common Sensor	IGRV/GRCS	Senior Year (SAR)	Senior Year (SIGINT)	Senior Year (DDL)	Senior Year (EO)	TAC RECCE (ATARS)	BGPHES	High Altitude Endurance	ABIT	
SUPPORTED PROGRAM	DATA LINK (Band)	GDDL (Ku)	IADL (Ku)	IADL (X)	IADL (X)	CDL (X)	IADL (X)	CDL (X)	CDL (X)	CDL (X)	CDL (X)	
ETRAC	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
TRAC-MIST	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
Guardrail	IGDL 2,3K (X, Ku)	√	√	√	√	√	√	√	√	√	√	10.71 Mb/s ONLY
Multi-role Data Link	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
DGSI (ALS-CARS)	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
IDGS	IGDL (X)			√	√	√	√	√	√	√	√	
JSIPS	CDL (X,Ku)	√	√	√	√	√	√	√	√	√	√	
MOBSTR	IGDL (X)			√	√	√	√	√	√	√	√	
OLOA	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
OLOH	IGDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
SY-17	IGDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
Flight Test MIST	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	
CHBDL	CDL (X)			√	√	√	√	√	√	√	√	
SY-11	CDL (X, Ku)	√	√	√	√	√	√	√	√	√	√	

Table 4.2: CDL Interoperability Matrix [Ref. 9]

2. Time Division Multiple Access (TDMA)

There are three basic techniques in which a communication system accesses a satellite transponder: FDMA (frequency division multiple access), CDMA (code division multiple access), and TDMA. As stated previously, CDL utilizes TDMA exclusively, and therefore, it will be the only access technique discussed.

TDMA works in the time domain and is applicable only to digital systems because information storage is required. Only one user (i.e., earth station) appears on the satellite transponder at a given time. That user has full and exclusive use of the transponder bandwidth during its time-assigned segment. Since only one carrier appears on the transponder at a given time, intercarrier intermodulation (IM) products (i.e., noise) cannot be developed and the traveling-wave tube (TWT) -based high power antenna (HPA) of the transponder may be operated at full power, increasing transponder efficiency (see section C of this chapter). Another advantage of TDMA is its flexibility. There is no problem with non-uniform transponder access because time-slot assignments are easy to adjust [Ref. 6:p. 394-405].

An important requirement of TDMA is that transmission bursts do not overlap. To ensure nonoverlap, bursts are separated by a guard time; the longer the guard time, the greater is the assurance of nonoverlap. However, an increase in the guard time reduces the efficiency of the system. The amount of guard time is a function of system timing. Typical guard times for operating systems are on the order of 50-200 ns. Figure 4.1 shows a typical TDMA frame. A frame is a complete cycle of bursts, usually with one burst per access. Burst length can be made a function of the traffic load of a particular access at a particular time; burst lengths are generally nonuniform. The frame period is the time required to sequence the bursts through a frame. For high-capacity systems such as CDL, frame periods vary from 100 μs to over 2 ms. For example, the INTELSAT TDMA system has a frame period of 2 ms.

The number of accesses per frame can vary from 3 to over 100 and is a function of the transponder bandwidth and the digital modulation employed. Figue 4.1 also shows a typical burst format, or access subframe. The first segment of the subframe is called the CR/BTR (carrier recovery/bit timing recovery). This symbol sequence is particularly necessary on a coherent PSK system such as CDL, where the CR is used by the PSK modulator in each receiver to recover the local carrier and the BTR is used to synchronize the local clock [Ref. 6:p. 404].

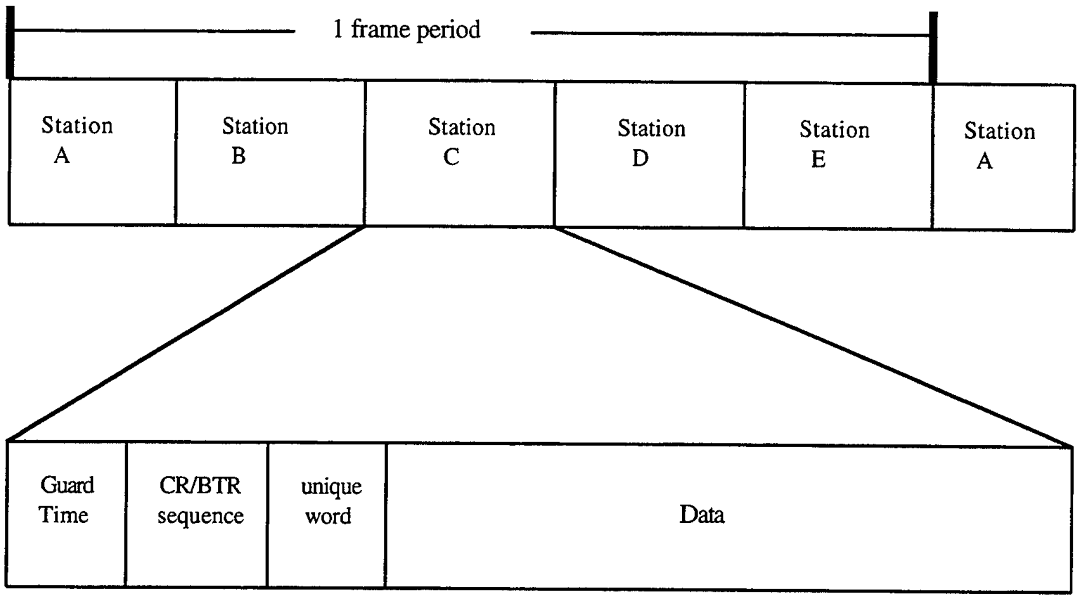


Figure 4.1: Typical TDMA frame and burst formats [Ref. 6:p. 405]

The next bit sequence in the burst subframe is the unique word (UW), which establishes an accurate time reference in the received burst. The primary purpose of the UW is to perform the clock alignment function. However, the UW can also be used as a transmit station identifier.

The loss of either the CR/BTR or the UW is fatal to the receipt of a burst. Large blocks of data can be lost due to a "skew" or a slip of alignment. TDMA systems are designed for a probability of miss or false detection of 1×10^{-8} or better to maintain a required threshold bit error rate (BER) of 1×10^{-4}. A BER of approximately 1×10^{-3} is the point where supervisory signaling will be lost. The design threshold of 1×10^{-8} will provide a mean time to miss or false detection of several hours with a frame length on the order of 1 ms [Ref. 6:p. 406]. There are ways in which TDMA system designers can address improved error and threshold performance to increase efficiency, and they are discussed in depth in Freeman [Ref. 6].

3. CDL Modulation Techniques

The CDL level A system specification manual [Ref. 8] lists the current criterion for CDL modulation as phase shift keying (PSK) for all data rates listed in Table 4.1. It also discusses using Direct Sequence-Spread Spectrum (DS-SS) for future applications, although only at a data rate of 200 Kbps. With the data compression technology currently available, the proposed video transmission system will operate at data rates around T1 or possibly 2T1 (see Chapter VII: Link Budgets). Therefore, the following sections will describe PSK modulation and provide an overview of spread spectrum technology.

a. Phase Shift Keying

There are three basic types of modulation techniques: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). For systems using higher data rates, such as CDL, a form of phase modulation called phase shift keying (PSK) is often utilized. PSK conveys digitized information by shifting the phase of a carrier relative to a reference phase. The phase will shift to represent the desired value or values. A two phase system, referred to as binary PSK (BPSK), uses one phase of the carrier frequency for one binary state and the other for the other binary state. The two phases are 180° apart and are detected by a synchronous detector using a reference signal at the receiver that is of known phase with respect to the incoming signal. This known signal is at the same frequency as the incoming signal carrier and is arranged to be in phase with one of the binary signals. This is called coherent detection. In general, PSK is used in situations where phase coherence between the transmitter and receiver remain constant over a relatively long period [Ref. 6:p. 811].

Another form of PSK utilized by CDL is quadrature-phase shift keying (QPSK), where two binary channels are phase multiplexed onto one tone by placing them in phase quadrature as shown in Figure 4.2.

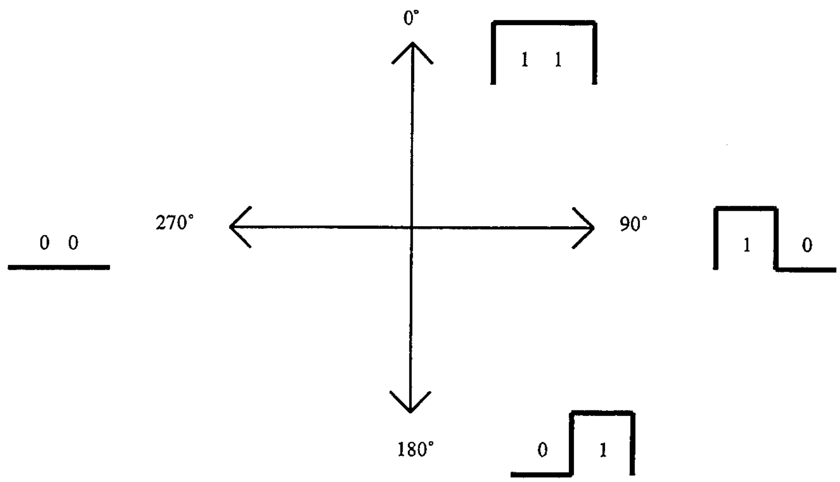


Figure 4.2: QPSK Modulation

For CDL Return Link (RL) data rates of 400 Kbps and below, BPSK modulation is utilized. For all other higher data rates (see Table 4.1), the modulation technique used is QPSK.

b. Spread Spectrum Technology

Fundamentally, a spread spectrum signal is one in which the transmitted bandwidth is substantially larger than that of the bandwidth of the information itself. The spreading is accomplished by means of an independent code signal, referred to as a pseudonoise (PN) sequence or code. To recover the original signal, the received signal must be despread by its correlation with a synchronized replica of the spreading code used.

There are several benefits associated with the use of spread spectrum technology in a TDMA application such as CDL. A properly designed and implemented SS signal will have a low power spectral density (PSD), and therefore, a non-spread spectrum receiver will interpret the SS signal as background or thermal noise. The PSD is a graphical or mathematical expression that enables examination of the frequency distribution of the power transmitted and received by a given communication system.

A simple example will illustrate the fundamental concept of SS technology. Assume a BPSK signal with a carrier frequency (f_o) and a data rate of 1200 bps. It is further assumed an E_b/N_o of +15 dB is determined for the system. E_b is defined as the energy per bit and N_o is the noise power spectral density. The value of the E_b/N_o ratio is driven by the desired probability of bit error (P_b) for a given communication link. If a low P_b is desired, a relatively high E_b/N_o will be required. The resultant plot of the PSD is shown below in Figure 4.3.

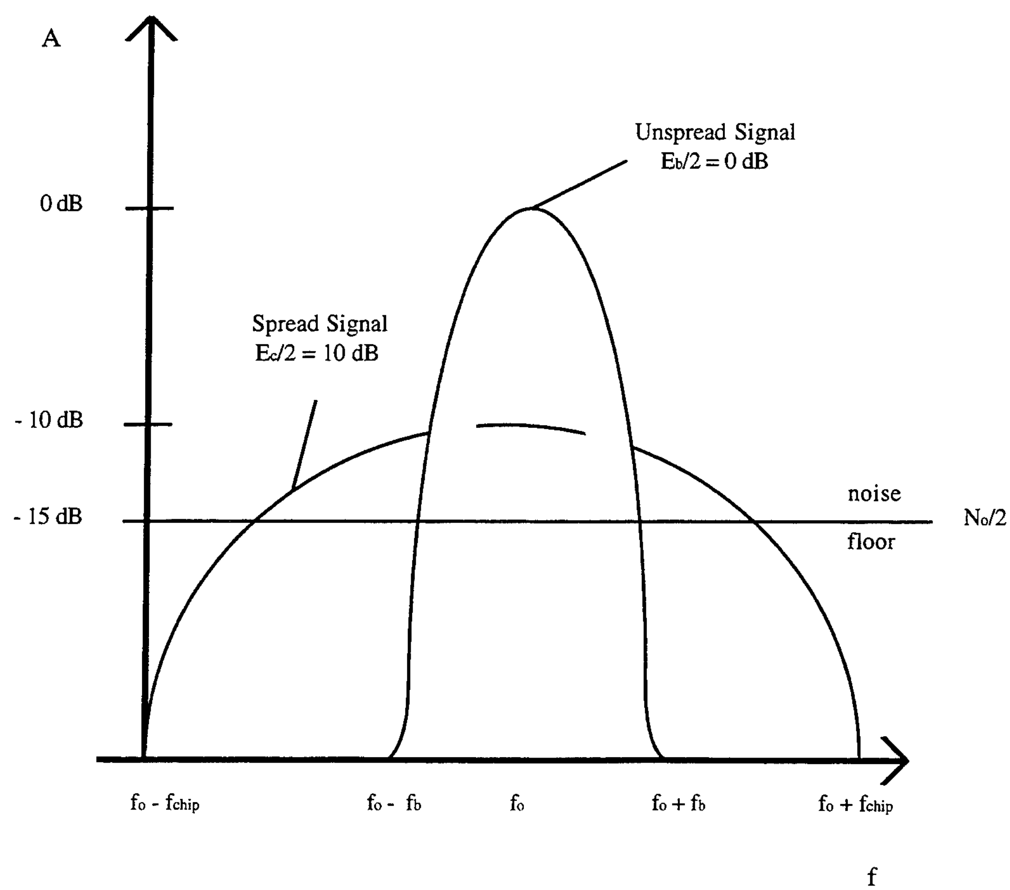


Figure 4.3: Spread Spectrum Power Spectral Density

The maximum point, $E_b/2$, of the PSD of the non-spread BPSK signal has been normalized to equal 0 dB. It follows that for E_b/N_o of 15 dB, the noise floor PSD $N_o/2$, is -15 dB. Next, the PSD of the signal after being spread with a chip rate of 12 KHz has also been plotted on Figure 4.3. Notice how the peak of the spread signal is now only 5 dB above the noise level.

As this example illustrates, a spread spectrum signal is harder to detect (Low Probability of Detection) and intecept (Low Probability of Intercept) than a conventional signal. In addition, since all signals other than the intended signal appear to the intended receiver as noise, jamming signal energy will be interpreted in the same way as noise. Therefore, a SS system is said to be jam resistant [Ref. 11:p. 4-9].

The benefits of incorporating spread spectrum technology into the Common Data Link are well documented. Unfortunately, SS is not presently being utilized for the data rates applicable to the proposed system.

B. VIDEO DATA COMPRESSION

1. Overview

A digital video signal consists of a complex analog signal (RS-170 Monochrome, NTSC Color composite) which has been digitally sampled, converting all of the images, colors, brightness and contrast of the original picture signal into 1s and 0s. Military applications of digital video transmission require picture quality to be maximized, while bandwidth limitations force data link channel bit rates to be minimized. By utilizing digital video compression technology, data transmission rates can be decreased without sacrificing picture quality.

The digitization and compression process begins when a video camera's composite analog video signal enters the Video Compression Encoder's front end. This composite signal is then broken down into its RGB (red, green, blue) and sync components. The three color components pass through individual analog to digital (A/D) converters and are then stored as bits in the Encoder's memory. Each separate image or frame of video information can be processed and stored this way, with a single frame of digitized video comprised of over 7 million bits. At a full frame rate of 30 frames/sec (full motion), over 200 Mbps (see Chapter III) of digital video information would need to be sent from one point to another to see what the camera is focused on. The goal of video compression is to preserve as much detail as possible from the original analog video picture, while simultaneously discarding as much unnecessary and redundant digitized video information as possible [Ref. 12].

Video compression is accomplished by utilizing one of the several methods of frequency transformations. Two of these transforms are frequently discussed in the literature: the Discrete Fourier Transform (DFT) and the Discrete Cosine Transform (DCT). As the DFT is generally used for spectral analysis and filtering, only the DCT will be discussed. Discriptions of the Discrete Fourier Transform as well as other methods may be found in Rabbani [Ref. 13].

2. Discrete Cosine Transformation (DCT)

The DCT method is a sinusoidal transform algorithm which has been found to work quite well in compressing television image data. The N x N image is first divided into n x n blocks. Each block is then placed through the Forward Discrete Cosine Transform which is defined as [Ref. 13:p. 108]:

$$F(u,v) = \frac{4C(u)C(v)}{n^2} \sum_{j=0}^{n-1} \sum_{k=0}^{n-1} f(j,k) \cos\left[\frac{(2j+1)u\Pi}{2n}\right] \cos\left[\frac{(2k+1)v\Pi}{2n}\right]$$

where u and v are the horizontal and vertical indices of the transformed block and j and k being the horizontal and vertical indices of the original block. F(u,v) is the pixel value at the position u,v in the transform block and f(j,k) is the pixel value at the position j,k in the original block. C(u) and C(v) are defined as:

$\frac{1}{\sqrt{2}}$ for u,v = 0 and 1 otherwise

An example of this transform using an 8 x 8 sub-block is shown in Tables 4.3 and 4.4. Table 4.3 is the original block, while Table 4.4 is the transformed block.

	j=0	j=1	j=2	j=3	j=4	j=5	j=6	j=7
k=0	139	144	149	153	155	155	155	155
k=1	144	151	153	156	159	156	156	156
k=2	150	155	160	163	158	156	156	156
k=3	159	161	162	160	160	159	159	159
k=4	159	160	161	162	162	155	155	155
k=5	161	161	161	161	160	157	157	157
k=6	162	162	161	163	162	157	157	157
k=7	162	162	161	161	163	158	158	158

Table 4.3: Original 8 x 8 Image Block [Ref. 13: p. 116]

	u=0	u=1	u=2	u=3	u=4	u=5	u=6	u=7
v=0	315	0	-3	-1	1	-1	-1	0
v=1	-6	-4	-2	-1	-1	0	0	0
v=2	-3	-2	-1	1	0	0	0	0
v=3	-2	-1	0	0	0	0	0	0
v=4	0	0	0	1	0	0	0	0
v=5	1	0	1	0	0	0	0	0
v=6	0	0	0	0	0	1	0	0
v=7	-1	1	1	-1	1	0	0	0

Table 4.4: Transformed 8 x 8 Block

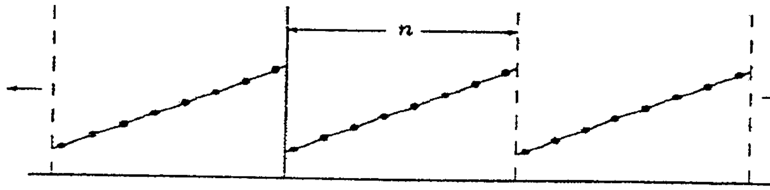
The Inverse Discrete Cosines Transform is defined as [Ref. 13:p. 108]:

$$f(j,k) = \sum_{u=0}^{n-1} \sum_{v=0}^{n-1} C(u)C(v)F(u,v)\cos[\frac{(2j+1)u\Pi}{2n}]\cos[\frac{(2k+1)v\Pi}{2n}]$$

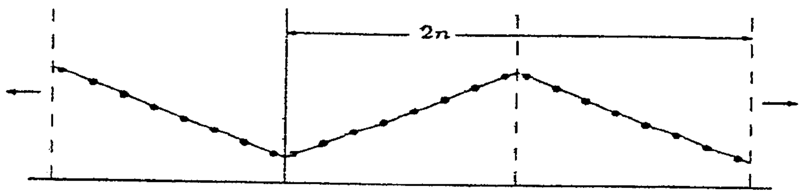
F(u,v), f(j,k), C(u), and C(v) are defined as above. Upon application of the Inverse DCT, the pixel values in the original block are restored.

The DCT has a higher compression efficiency over the DFT since it avoids the generation of spurious spectral components. By examining this phenomenon in more detail, it is obvious why DCT has become, by far, the most widely used transform for image compression.

The DFT is the discrete Fourier series representation of a finite-duration sequence, and as such, there is an implicit periodicity of the sequence resulting from a sampling in the frequency domain (see Figure 4.4a). Replicating the original sequence in this manner often creates severe discontinuities between the segments. These discontinuities result in spurious high frequency components that can considerably reduce the efficiency of the transform. Although these spurious components are not really part of the original sequence, they are required to reconstruct the sharp boundaries in the periodic sequence. Attempting to increase the transform efficiency by discarding these components results in reconstruction errors at the boundaries. In image coding, where the image is broken up into blocks of pixels to form 2-D sequences, these reconstruction errors result in blocking artifacts (i.e., the boundaries between adjacent blocks are highly visible) [Ref. 13:p. 110].



a) DFT periodicity



b) DCT periodicity

Figure 4.4: Implicit periodicites of the DFT and the DCT [Ref. 13]

To eliminate the boundary discontinuities, the original n-point sequence can be extended into a 2n-point sequence by reflecting it about the vertical axis. The extended sequence is then repeated to form the periodic sequence required for the discrete Fourier series. As shown in Figure 4.4b, this periodic sequence does not have any discontinuities at the boundaries, and no spurious spectral components are introduced in the DFT. This process of taking the 2n-point DFT of the extended n-point sequence is identical to the DCT of the original n-point sequence. Therefore, the DCT does not generate spurious spectral components, so coding efficiency remains high and blocking artifacts are greatly reduced.

3. Adaptive Digital Video Standard (ADVS) Algorithm

All existing video compression algorithms currently utilize one of the two major classifications of coding schemes: intraframe and interframe coding. Intraframe coding takes advantage of the similarity of adjacent picture elements within each separate and individual frame or picture, while interframe coding relies upon the high degree of correlation in picture content from frame to frame. During intraframe coding, each individual line or individual group of pixels is scanned during every field, up to 60 times per second. The intraframe method of compression is superior when either the camera or the source material is moving, as no blurring of the compressed image will occur, and also no settling time is required for the image to stabilize. Each and every image will be a still frame suitable for analysis or image enhancement [Ref. 12].

Through the use of intraframe coding, the ADVS Adaptive Digital Video Standard algorithm, developed by Enerdyne Technologies, Inc., is exactly what its name implies, adaptive. Vertical and horizontal resolution, quantization, luminance, chrominance, greyscale, and field rate resolution are all functions of picture complexity, and the user is able to capitalize upon the interdependencies among all of these elements. If the user desires a higher horizontal resolution, then the tradeoff is that the video compression system sends fewer than all of the picture fields (i.e., less than full-motion) at the same fixed bit rate. When connected to a dumb terminal via the RS-232 data communications port, the Enerdyne system can provide constant system status and changeable parameter information to the user [Ref. 12].

The ADVS capitalizes on the proven performance of the Discrete Cosine Transform (DCT) algorithm for compressing video signals. In the Enerdyne ADVS/DCT Encoders the individual color components are manipulated and arranged such that separate 8 x 8 pixel blocks are produced. The DCT algorithm then compares these 8 x 8 pixel blocks lying adjacent to each other. Subsequently, the encoder's internal microprocessor performs a DCT coding on the blocks to produce the DCT coefficients, which are then encoded into a compressed data stream using vector quantization. Each image or frame of video information will create a different size 'file' after being digitized, depending on the picture content of that image. Since the file size produced varies with picture content and the overall transmission rate must be fixed, the compression method must automatically alter some key parameter in exchange for consistent file size. These parameters can be:

horizontal resolution (pixels per line), quantization level (resolution of pixels within a given tile), and/or temporal resolution (frames per second). Enerdyne ADVS systems can be operated at data rates from 300 bps to 12 Mbps, with programmable features including horizontal resolution, quantization level, and crop (active image area) selection available via remote RS-232 control. These functions can be selected or changed while the unit is actually in use, allowing the user the opportunity to view changes made instantly [Ref. 6].

All video compression systems take advantage of the usual relative redundancy of pixels or groups of pixels lying adjacent to each other in any given picture or field. For example, if 100 adjacent pixels on the same TV scan line are identical in color and intensity, the video encoder's internal circuitry sends an encoded signal stating that 'this pixel and the next 99 are all the same'. This compression technique thereby saves bandwidth when compared to sending pixel values for every one of the identical 100 pixels. Much of the ADVS algorithm is dedicated to the removal of redundant and repetitive signals, since about 25% of an NTSC video signal contains only vertical and horizontal synchronization information rather than pure video image information. Reducing the end of line and end of field signals in a digital data stream to a few bits each allows the remainder of the signal to be transmitted more slowly and with no picture degradation. In addition, the manipulation of each block further increases the compression capabilities of the Enerdyne algorithm [Ref. 12].

4. Existing Commercial Hardware

Presently, there are several video compression systems that are available in the commercial marketplace. This section will describe one of them, the Model SVC-3, a secure video compression system made by LORAL-MICROCOM. The SVC-3 was chosen because it is a proven airborne system with built-in encryption and the capability for Forward Error Correction (FEC). The SVC-3 utilizes the ADVS compression algorithm that was previously discussed, with LORAL-MICROCOM providing the encryption and FEC for the system [Ref. 14].

The Model SVC-3 is a combination Color Video Compressor/Encryption unit designed for airborne use. Figure 4.5 shows a block diagram of a typical airborne encoder/compressor and ground station decoder/decompressor system. The SVC-3 contains a color video compressor assembly, KGV-68 encryption device, non-volatile key storage and all necessary support circuitry to provide a complete link from the output of a video camera to the input of a telemetry transmitter. Programming is accomplished using an RS-232 terminal interface. As an option, the SVC-3 contains provisions for multiplexing asynchronous serial data at up to 100 Kbps into the digitized video data stream [Ref. 12].

The function of the Color Video Compression Encoder is to digitize and compress a standard analog video signal which is provided from the video camera. The SVC-3 accepts several input formats: NTSC Color composite, RS-170 Monochrome, Y/C (S-VHS), or European PAL Standard; all of these are program selectable via an RS-232 link. By using a digitized television signal, added capabilities such as the multiplexing of both digital data and voice into the bit stream are possible [Ref. 12]. This feature would allow an onstation aircrew to instantaneously describe an image being transmitted. Typical available output bit rates are 5 Mbps, 2.5 Mbps, 1.5 Mbps, and 625 Kbps, although any requirement for a specific data rate (i.e., CDL compliance) can be met with a minor software modification [Ref. 15].

The encryption of the digitized video data is accomplished using a COMSEC KGV-68 Encryption Device included in the SVC-3. It requires serial Non-Return to Zero (NRZ-L) from the video compressor. To provide an output, the KGV-68 requires a

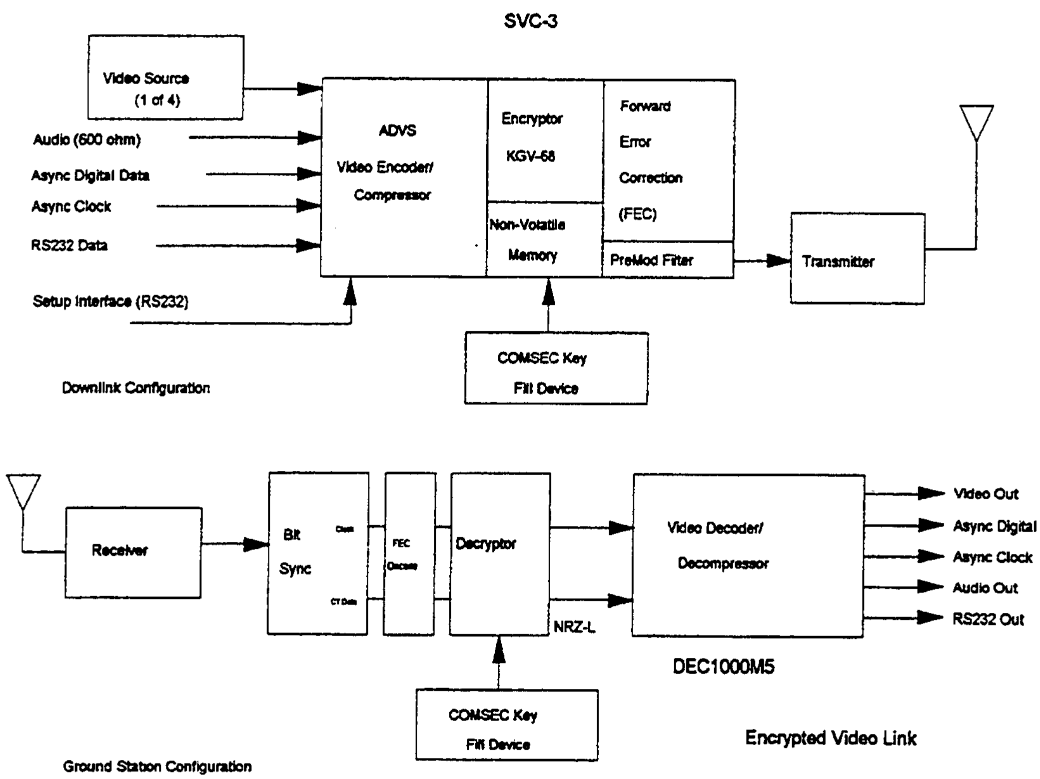


Figure 4.5: Encrypted Video Link Block Diagram [Ref. 12]

Cryptovariable Key, entered into a non-volatile memory through the Key Fill Input using a COMSEC fill device (KOI-18 or KYK-13). The Automatic Transmitter Inhibit function built into the unit assures that no power is provided to the transmitter until a Crypto Key has been down loaded from the memory into the KGV-68. This ensures that there is no transmission of unencrypted data [Ref. 12].

Forward Error Correction (FEC) may be inserted or bypassed in the encrypted data stream under terminal control (via RS-232 connector), and is provided to minimize the possible bit error rate under marginal conditions. This feature uses the Reed-Solomon algorithm to add check bits to the data stream. The added check bits contibute to a 12.5%

data redundancy. The FEC consists of a chip and support circuitry designed for this purpose, which automatically adjusts the clock in the compressor to make up for the redundant bits, thus keeping the transmitted bit rate at a constant value. Therefore, the addition of FEC provides the benefit of minimized bit error rates, without sacrificing a decrease in transmission data rates [Ref. 12].

C. TRAVELING WAVE TUBE (TWT) AMPLIFICATION

In order to successfully meet power requirements, all communication systems need some type of power amplification. The CDL communication suite utilizes one of the most commonly used amplifiers, the traveling wave tube (TWT). TWT amplifiers operate most efficiently when driven to an operating point at or near saturation. However, when two or more carriers drive the TWT near its saturation point, excessive IM products are developed. These can be reduced by reducing the drive, which in turn, reduces the amplifier efficiency. This reduction in drive power is called backoff.

A rough rule of thumb is that for approximately every decibel of backoff, IM products drop 2 dB for the multicarrier case. Also, for every decibel of backoff on TWT drive power, the TWT output drops 1 dB, causing inefficiency in the use of the TWT. As the number of carriers is increased on the transponder, the utilization of the available bandwidth becomes less efficient.

The 5 - 10 dB losses associated with TWT backoff are more prevalent in FDMA systems, where a transponder is divided into several frequency band segments (i.e. multicarrier). Since CDL is a TDMA system, only one carrier appears at the transponder input at any one time. Therefore, the TWT can be run to saturation minus a small fixed backoff to reduce waveform spreading, resulting in more efficient use of the transponder [Ref. 6:p. 395-404].

The specifics of the CDL TWT amplifiers for both X- and Ku-band are listed below [Ref. 8:p. 65-68, Appendix 1A].

Size:	9.30 x 1.88 x 1.71 (in)
Weight:	1.0 lb
Input Power:	350 Watts max
Helix:	4200 VDC to 4600 VDC at 15 mAdc
Cathode current:	140 mAdc max
Frequency Range:	14.300 to 15.550 Ghz (Ku-band) 10.100 to 10.600 Ghz (X-band)
Noise Figure:	35 dBm max (Ku-band) 30 dBm max (X-band)
RF Output power:	70 Watts min, 100 Watts max (Ku-band) 80 Watts min, 100 Watts max (X-band)

The operating power output of the CDL TWT amplifiers is between 1 and 50 Watts, with provisions included for control of the power output in 1 dB steps between the minimum and maximum values. The TWT amplifiers provide for sufficient power amplification in both X- and Ku-bands, to meet the effective isotropic radiated power (EIRP) requirement.

V. ANTENNA SUBSYSTEM

A. ANTENNA OVERVIEW

The antenna subsystem is one of the most important components of this proposed video link, since it provides the means of transmitting to and receiving from the available satellite. In addition to providing the necessary gain for adequate transmission and reception, the antenna must have the beam-shaping characteristics to avoid interference with other satellites and systems. There are two basic antenna technologies that will be discussed in this section: reflector antennas, and phased array antennas. Both technologies have advantages and disadvantages for use in aircraft that will be discussed in following sections.

There are two primary installation factors of concern for airborne satellite link antennas. The first is the ability to mount an antenna with minimal aerodynamic and structural disruption to the aircraft. The objective is to avoid costly structural modifications along with the necessary airframe requalifications that must be performed. The second factor is that of the antenna subsystem weight and its effect on the aircraft's ability to perform its mission. In addition to installation factors there are three primary performance factors concerning antennas. The first is antenna efficiency, or getting the required power to and from a geosynchronous satellite. The second is radiation coverage, due to the requirement that we will need to minimize interference with adjacent satellites. Lastly, the antenna's ability to point and track accurately will be critical on a rapidly rolling platform such as an aircraft.

Due to the high data rates required for the transmission of motion video and the constraint of available satellites (see Chapter VI), the primary frequency bands of interest while discussing antenna systems are the X-band and the Ku-band. The X-band has uplink frequencies of approximately 8 GHz and downlink frequencies near 7 GHz. The commercial Ku-band equivalents are in the 14 GHz and 11 GHz ranges. The frequency ranges are important because they help determine the antenna gain for a given antenna diameter. The Navy's UHF satellite communications network has insufficient bandwidth capacity for the transmission of motion video although still frame image transmission would be possible at a relatively low rate. Because of these limitations UHF satcom antenna systems will not be discussed in detail in this section. The considerations of both antenna installation and performance must fall under affordibility limitations recently made much smaller due to the shrinking defense budget. In addition to the above, technological risks are of valid concern when choosing an antenna system, primarily with regards to the phased array technologies, although this field is maturing rapidly.

B. ANTENNA PERFORMANCE

1. Performance Review

With regard to antenna performance there are several important performance measures that must be addressed. The most important performance measure for antenna transmissions is the Effective Isotropic Radiated Power (EIRP). The EIRP is essentially the product of antenna gain and input power. Therefore, up to a practical limit,the limitations on the physical size of an aircraft's antenna can be compensated for by increasing the power to the antenna. Reducing the antenna size however will increase the propagated beamwidth which may in turn cause interference problems with adjacent satellites. For antenna reception, however, the Gain-to-Noise Temperature Ratio (G/T) is the primary performance figure of concern. The G/T value is a measure of a receiving system's ability to receive low-level signals effectively. The gain of the antenna subsystem is derived primarily by the performance of the antenna itself, the Low-Noise Amplifier (LNA), and that of the receiver. The noise is that of the contributions from sky and earth noise sources within the main beam, and from the amplifier and receiver noise.

The beamwidth of an antenna is an important consideration in avoiding possible interference with adjacent satellites. The beamwidth of an aperture antenna in degrees is given by the relationship:

$$\text{Beamwidth} = \beta\left(\frac{\lambda}{D}\right)\text{deg}$$

where D is the aperture in the plane of the radiation pattern, λ is the wavelength, and β is a correction factor equating to 50.6 for a rectangular aperture, and 58.4 for a circular aperture antenna [Ref. 16: p. 3-3]. The higher the frequency band used the more narrow the beamwidth will be for a given antenna diameter.

Antenna gain is a fundamental parameter in link engineering. The gain is conventionally expressed in decibels and is an indication of the antenna's concentration of radiated power in a given direction. The antenna gain expressed is the gain over an isotropic antenna. An isotropic antenna is a theoretical antenna with a gain of 1 (0 dB) which radiates equally in all directions [Ref. 6:p. 283]. The gain of an antenna is also a function of the frequency used. In the case of a parabolic dish antenna, the gain can be expressed by:

$$G_{db} = 20 \log F_{MHz} + 20 \log D_{ft} + 10 \log \eta - 49.92 \text{ dB}$$

where F is the operating frequency in MHz, D is the diameter of the dish in feet, and η is the aperture efficiency expressed as a decimal. Typical values for η range from 0.50 to 0.70. The gain of phased array antennas is related to the number of elements in the phased array, and the power transmitted from each of the elements. Gain for phased array antennas will be discussed later in this chapter.

2. Antenna Pointing and Tracking

The communications satellites that are being considered for this study are either in geostationary or geosynchronous orbits. Geostationary orbits are those whose positions remain fixed over a point on earth. Geosynchronous satellites are those in an inclined orbit and are in motion with respect to a point on earth, although the inclination is typically small. Geosynchronous satellite tend to drift in small suborbits shaped as figure eights over the earth's surface. Both orbit types are approximately 35,822 km (19,340 nm) in altitude above the earth surface. These orbits do drift slightly and require satellite stationkeeping to maintain relatively precise locations. Depending upon the antenna aperture, even ground station antennas may require antenna pointing corrections to maintain the desired signal to geostationary satellites. For a mobile platform such as a P-3 aircraft which not only transits thousands of mile but also pitches, rolls and changes azimuth rapidly, antenna pointing and tracking is necessary in maintaining a viable link. The term pointing will refer to the initial aiming of the antenna at the satellite, whereas tracking is the ability to maintain the antenna beam pointing at the satellite of interest.

There are two basic modes of operation to provide pointing and tracking:

-Automatic tracking (closed-loop tracking)

-Programmed tracking (open-loop tracking)

a. Closed-Loop Tracking

There are three basic types of active or closed-loop tracking. They consist of the monopulse, step-track, and conscan methods. The monopulse method was one of the first forms of satellite tracking. Monopulse tracking has taken its name from radar technology in that all the directional information that is needed is obtained from a single radar pulse. The monopulse tracking method uses multiple feed elements to obtain multiple received signals typically from the satellite's beacon channel. The relative signal levels received by the various feed elements are compared to provide azimuth and elevation angle pointing error signals. These signals are converted to error voltages proportional to the angle off-center from which a tracking algorithm provides corrective pointing guidance. With monopulse tracking systems the beam scanning can be performed at almost any arbitrarily high rate, therefore providing the potential for the high tracking rates needed on a mobile platform.

The step-track method also requires only a beacon signal or another dc signal proportional to the received RF signal level. In the step-track technique the antenna is periodically moved a small amount on each axis, and the level of the received signal is compared to its previous level. A processor converts these level comparisons into input signals for the servo or pointing system which will drive the antenna in directions that maximize the received signal level. In contrast to the above monopulse tracking which seeks a sharp null, the step-tracking technique seeks a signal peak, a method which is not as accurate. In addition, step-tracking requires low dynamic tracking requirements more suitable for ground-station geostationary pointing antennas. Because of the highly dynamic environment of an aircraft mounted antenna, the step-track method would be unsuitable for this application.

Conical scan tracking is a lobing technique developed for radars that uses a continuous rotation of the beam around the target. The continuous beam scanning is accomplished by mechanically or electronically moving the antenna feed which will put the antenna beam off axis as the feed is moved off its focal point. The feed is typically moved in a circular path around the focal point, causing a corresponding movement of the antenna beam in a circular path around the satellite to be tracked. Angle-error detection circuitry is provided to generate error voltage outputs proportional to the tracking error and with a phase or polarity to indicate the direction of the error. The error signal actuates the pointing system to drive the antenna in the proper direction to null the error to zero. Conscan tracking can be used for high or low target dynamics and only requires one RF channel and a single-beam feed. Its primary disadvantage is that it requires four pulses or short duration continuous signals to obtain tracking information and in the case for mechanically steered antennas is subject to mechanical reliability problems [Ref. 6: p. 485].

b. *Open Loop Tracking*

Open loops tracking utilizes a processor that calculates the required azimuth and elevation angles as a function of time. This type of processor is called an ephemeris processor due to its ability to reference tabulated satellite locations with respect to a time scale. The ephemeris processor uses an algorithm that calculates the relative direction of the required satellite with respect to the terminal (or aircraft) on a continuous or real-time basis. The algorithm has access to the memory that contains the forecast satellite location with respect to time, which requires periodic updating every 30 or 60 days. For mobile terminals the processor requires continuous positional updates. For this proposed system, these updates will be generated by either the aircraft's inertial navigation units or by a Global Positioning System (GPS) receiver.

The antenna is continuously pointed by interpolation between the values of precomputed time-indexed ephemeris information. With accurate information as to the actual satellite position and true satellite terminal position, pointing resolution can be as good as 0.10 degrees or lower. Because open-loop processes lack the feedback of closed-loop systems is it subject to several sources of error that are automatically corrected in closed-loop system. These error sources consist of atmospheric refractions, gravity or g-loads on antennas, mechanical misalignments and input data inaccuracies of terminal location, satellite ephemeris and absolute time.

Open-loop tracking is probably best suited for terminals that have to rapidly acquire or slew. In addition, this method is also effective for wider beamwidth antennas such as airborne antennas, where the beamwidth is sufficiently wide to accommodate the entire geostationary suborbit. There exist military ephemeris processors that may have in memory ephemeris data for up to 20 satellites. Considering these advantages, an open-loop tracking system appears to be the preferred method of antenna pointing for this proposed subsystem [Ref. 6: p. 487].

C. REFLECTOR ANTENNAS

The most frequently used antennas for satellite communications are the parabolic dish type reflector antennas or derivatives of it. The reflector antenna technology is based on that of optical reflectors. This technology consists of a source of microwave energy, typically from an antenna feed horn radiating from a focal point on a parabolic reflector surface. This surface causes a field of parallel rays upon reflection that is pointed at the intended receiver.

The most common type of reflector antenna is the prime focus feed antenna which consists of a single feed horn pointed directly at the reflector surface (see Figure 5.1). Dual-reflector antennas consist of a main parabolic reflector and a hyperbolic (Cassegrain) or elliptic (Gregorian) subreflector. The focal point of the subreflector element is coincident with the focal point of the main reflector which determines the focal length of the system. The advantage of having a dual-reflector antenna is that of improved efficiency due to several reasons. Careful shaping of the two reflector surfaces can lead to a substantial gain enhancement by controlling radiation pattern sidelobes and providing a more uniform illumination of the main reflector with less spillover of energy. Further efficiency gains are possible due to the fact that the potentially heavy feed antenna now radiates from behind the main reflector for less waveguide loss. Typically, efficiencies of Cassegrain-type ground based antennas are from 65-75% which is at least 10% above most front-fed designs [Ref. 6:p. 478]. In addition to efficiency gains, a dual reflector antenna reduces the front-to-back dimensions of the reflector assembly providing a possibly slimmer profile decreasing the aircraft blister profile.

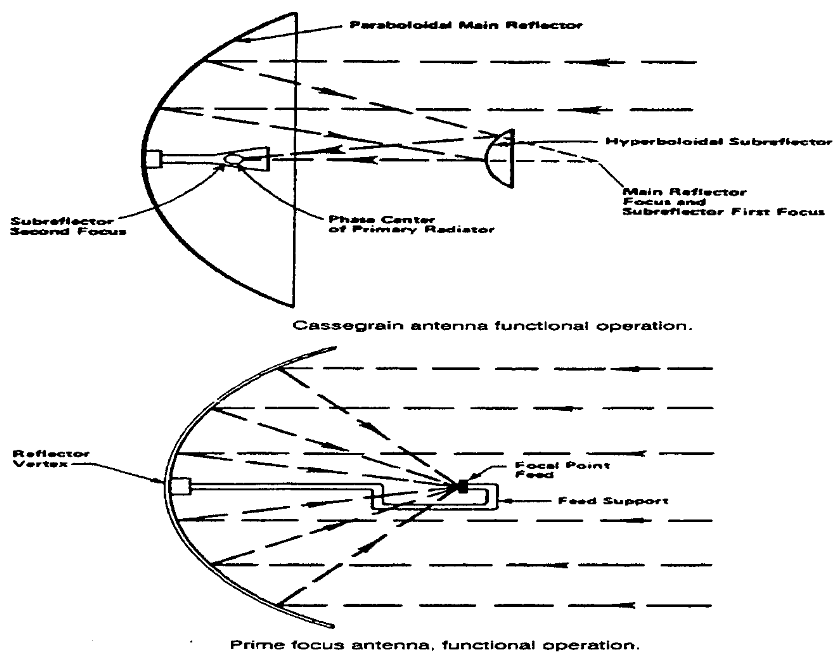


Figure 5.1: Parabolic Reflector Antennas [Ref. 6:p. 478]

In order to keep interference levels on both the up- and downlinks acceptable for satellite communications, antenna side-lobe envelope limits (in dB) of 32-25logθ relative to the main beam maximum level have been internationally adopted (where θ is the angular distance in degrees from the main beam lobe maximum) [Ref. 6:p. 477]. This limitation may dictate the type of reflector antenna that is allowable for this application.

Due to the significant aerodynamic and structural concerns of mounting a blister housing on the exterior of an aircraft, consideration should be given to elliptical-contoured reflectors. For low-profile requirements, elliptical reflectors offer significant size and weight advantages. Elliptical-contoured reflectors can efficiently radiate from a flush circular aperture as the elevation look angle is decreased. The receiver front end, solid-state amplifier, and pointing control hardware are all located on the pedestal assembly (see Figure 5.2). This design was developed at the Jet Propulsion Lab (JPL) for NASA's Advanced Communications Technology Satellite (ACTS) Mobile Terminal (AMT). The peak gain of this antenna in the 20 GHz range is approximately 23 dBi. Because the elevation beam of this antenna is so large, the antenna's elevation angle is fixed at 45°

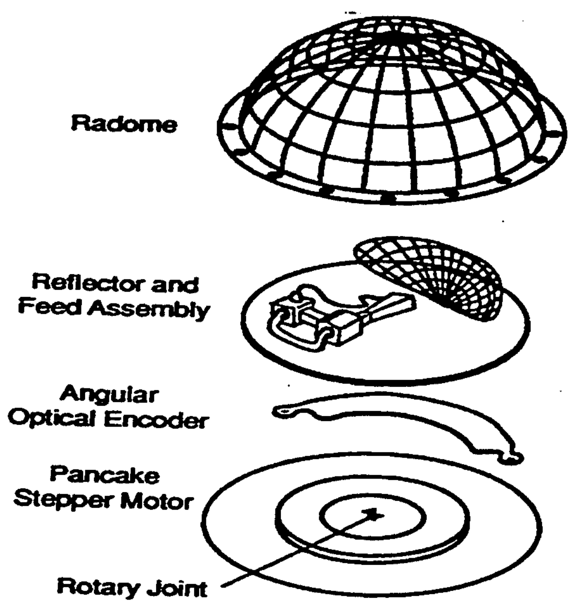


Figure 5.2: Elliptical-contoured Reflectors [Ref. 17:p. 3-7]

allowing the antenna to track a satellite beacon in azimuth only using a sinusoidal dithering motion at a 2 Hz rate. This antenna can fit under a radome of 23 cm diameter and 10 cm height [Ref. 17:p. 3-7]. Perhaps more importantly, this design may enable flush mounting on the fuselage preventing a large disruption to the aircraft's structural integrity.

D. PHASED ARRAY ANTENNAS

Phased array antenna technology offers many advantages for aircraft applications with the primary one being their relatively conformal configurations. This will minimize airframe and aerodynamic disruption. In addition to physical shape the antenna's ability to communicate simultaneously with multiple satellites, it's relative light weight and agile beam steering that allows for rapid compensation for platform motion all contribute to the increasing importance of phased array antennas. Until recently the high cost of phased array Transmit and Receive (T/R) modules made the application of the technology unpractical for many applications. Expanded commercial applications and continued government investment together with manufacturing improvements have driven down the cost of the T/R modules by over a factor of 10 in the last decade with continued price decreases due to many factors. This cost breakthrough opens the door for new uses for these antennas.

1. Phased Array Design Considerations

Phased array antennas are essentially a series of radiating elements whose amplitude and phase are manipulated electronically to enable beamsteering. The T/R modules mentioned earlier are typically located behind these elements and may contain phase shifters, a low noise amplifier (LNA) for receive, power amplifier for transmit, logic circuitry, power conditioning circuitry (switching circuitry), and a diplexer. A power divider feeds the modules by splitting the RF signal from an oscillator. The excitation voltages necessary to steer the beam are generated by changing the phase shifters in each T/R module or by passing the RF through a beamforming network before the T/R modules [Ref. 18:p. 60]. The beamforming logic is based on the interferometric principle (see Figure 5.3). In Figure 5.3, elements a and b are adjacent slots, or radiators, whose individual antenna patterns at maximum response look like the c pattern. If we want a signal from directly normal to the antenna plane ($\Psi=0$), the receiver processes all the returns simultaneously. However, if we want signals coming in from an angle ($\Psi=\Psi i$) as in d, we must develop a successive time delay from one slot to the next with devices called phase shifters-- either ferrites or the more modern surface acoustic wave (SAWS) devices. As seen in the multislot, interferometric pattern b, all slew angles are not available to achieve peak gain. The following relation, which determines peak gains, defines usable angles:

$$\sin \psi_i = \frac{(2i + 1)\lambda\pi}{rL} \quad , \qquad \text{[Ref. 19:p. 269]}$$

where i is an integer, r is the total number of radiators in a row, and L is the distance between slots. The phase shifters must be set accurately to ensure peak response and proper beamforming.

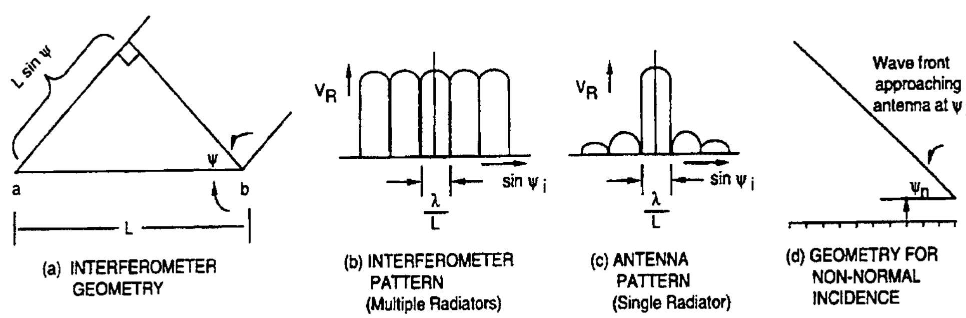


Figure 5.3: Phased Array Antenna Beamforming [Ref. 19:p. 270]

The T/R modules are the building blocks for phased arrays. The basic architectures for phased array antennas are derived from different ways to package the T/R modules (see Figure 5.4). The brick architecture consists of modules produced by integrating individual components onto a substrate which is located behind a radiating element and oriented orthogonal to the array surface. When cascaded together to form an array, these modules look similar to a layered brick surface. This type of architecture is designed to plug into a backplane and is suitable for a planar array design but holds limited promise for a curved conformal design. It is also thicker than is desired for a conformal antenna. The tile architecture provides very high levels of microwave component integration into a single substrate which is oriented parallel to the array surface. The tile architecture also allows a thinner profiles that will minimize aerodynamic disturbance to the airframe.

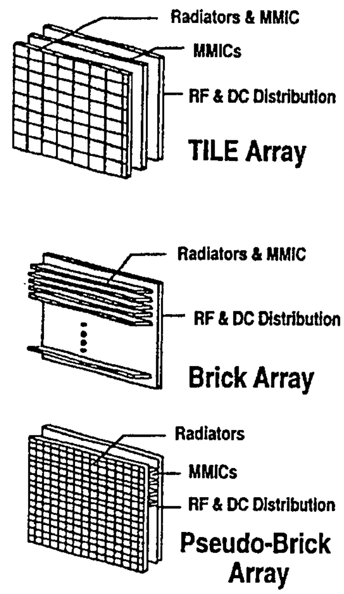


Figure 5.4: Phased Array Antenna Architecture [Ref. 18:p. 61]

The number of tiles or bricks or tiles can be increased depending upon the particular surface to achieve the necessary aperture. The sizing of the array aperture is driven by both the module count and the grid spacing requirement. Grid spacing is a function of the highest frequency which the antenna is to use. The higher that frequency, the closer spaced the grid just be. A higher frequency also means a smaller array for a required beamwidth. Because of this relationship, the lowest frequencies drive the maximum physical size of the antenna, while the highest frequencies required of the antenna drive the module grid spacing. In addition to these considerations, there are many factors that affect the final design (see Figure 5.5).

The physical aperture size of the phased array configuration is driven by several factors. The required beamwidth must be maintained in order to minimize interference to

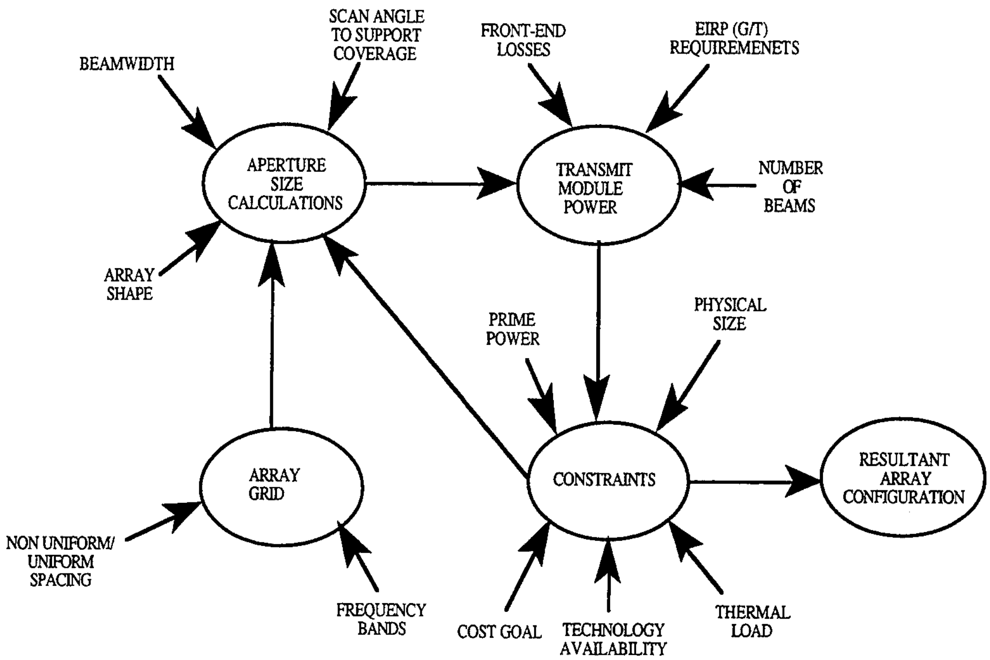


Figure 5.5: Phased Array Antenna Decision Tree [Ref. 20:p. 10]

adjacent communication satellites and to maintain the necessary EIRP. The more narrow the beamwidth requirement the larger the antenna aperture must be.

The scan angle specifications required to support the desired geographic regions with reasonable aircraft pitch and roll maneuvering will also drive the aperture size upwards. Unlike reflector antennas, phased array antennas suffer from a projected aperture problem. As the beam of the phased array is moved from perpendicular to the array, the projected aperture of the array decreases due to the loss of line-of-sight area of the array. Because of this effect, as the scan angle increases such as due to aircraft rolling, the beam size will increase and the gain will drop, lowering the antennas performance considerably. This effect must be considered when sizing an array to meet EIRP and transmitter gain (G/T) requirements of large angles [Ref. 18:p. 60].

The transmit module power requirement is linked to the aperture size calculations. The power requirement is driven by link budget computations specifying a particular EIRP (G/T) requirement. This power will be subject to transmission losses in the antenna itself which must be accounted for. Due to the phased array capability of multiple beamforming the power may also be divided among the multiple transmission beams.

A problem of particular importance to phased arrays is that of heat generation in the Monolithic Microwave Integrated Circuits (MMICs). If the array cannot meet reliability goals due to excessive heat generation, the array size may have to be expanded to allow for lower power amplifiers or active cooling systems may be required.

Before the resultant array configuration can be determined various constraints must be considered. The physical size of the array may be limited by the available space on the airframe that is not taken by the empennage or other antennas. The curvature of the airframe's tube structure also limits the size of a flat planar array which may necessitate using a conformal configuration. Both the flat planar array and conformal array will suffer from the projected aperture problem discussed earlier. One solution to ease slant angle losses during rolling maneuvers would be to increase the aperture to the point where the link can be maintained at nearly all aircraft attitudes, however the ever present cost constraints will likely limit array size and therefore limit link availability. As seen in Figure 5.5 there are numerous conflicting demands that will be factored in the design process before the final array configuration is determined. Fortunately, the many advantages of phased array antennas have pushed the research in radiating elements, MMICs, beamforming networks and compensation techniques allowing the performance tradeoffs to be less pronounced.

2. System Integration

The integration of a phased array antenna subsystem on the top of the fuselage of a P-3C aircraft consists first of determining an approximate size and weight of the proposed array. This is determined with the aid of a power link budget analysis that will be addressed in Chapter VI. Optimally if the size of the required array is sufficiently small, than a single flat array on top of the aircraft rather than a conformal configuration would be necessary. Another possibility would be to install two arrays slightly displaced off the top of the fuselage to further ensure coverage during rolling maneuvers (see Figure 5.6).

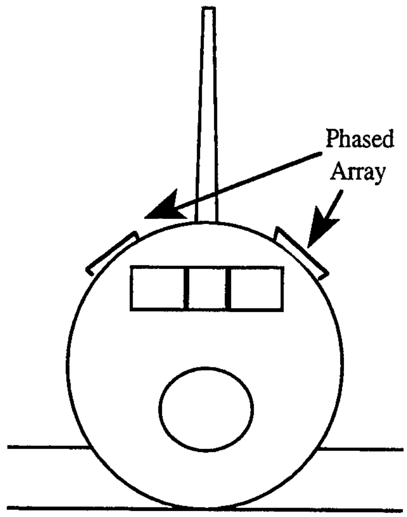


Figure 5.6: Phased Array Antenna Mounting Option

Installation will consist of the physical mounting of the antenna to the outer fuselage and then cutting the necessary electrical access holes through the aircraft skin. Some preliminary power and weight estimates from a Boeing Defense & Space Group briefing in February 1995 to the Naval Air Systems Command (NAVAIR) call for a Ku-band antenna requiring 2000 watts of DC power and an weight of approximately 40 pounds. This weight will not significantly affect aircraft weight and balance requirements. The primary aircraft dimensional constraint is that of the fuselage outer diameter of 11 feet and 4 inches which may form a limitation on slant angle EIRP, particularly during any roll maneuver away from the satellite. During routine ASUW patrols the P-3C roll angles are typically limited by the pilot to less than 30 degrees for crew comfort; however, during active prosecution, coordinated rolls of up to 70 degrees are a possibility. To maintain a viable link through all flight envelopes would probably require a very costly solution using multiple arrays about the aircraft upper fuselage. Therefore the link budgets of Chapter VI will consider roll angles of 30 degrees or less as a flight envelope limitation for transmission.

The proposed link may be duplex, however the emphasis is on the transmission of information generated by the aircraft sensors to the ship or shore installation rather than the receipt of high data rate imagery. For that reason, only simplex power link budgets from the aircraft to the user ground station will be discussed in the link budget analysis. This will ease the constraints on antenna size limitations because the forward link will require a significantly smaller antenna for proper operation. Further details on link power will be addressed in the following chapter.

E. POLARIZATION CONCERNS

Polarization describes the behavior of the far-zone electric field radiated from an antenna. Common polarizations are right-hand circular, left-hand circular, vertical linear, and horizontal linear. In order to eliminate polarization mismatch loss between a transmitting and receiving antenna, both antennas must have the same polarization. Left- and right-hand circular polarization are said to be orthogonal (i.e., a left-hand circular polarized transmitting antenna will not excite a right-hand circular polarized receiving antenna). The same is true of vertical and horizontal linear polarization. However, a circular polarized transmitting antenna can excite a linear polarized receiving antenna; the penalty is 3 dB of polarization mismatch loss. For a link suffering from polarization mismatch loss, the effect must be compensated for elsewhere by increasing the radiated power, increasing the antenna, size, decreasing the data rate, etc. [Ref. 16:p. 3-4]

Some communications satellites use polarization discrimination to obtain frequency reuse. These are primarily commercial satellites such as INTELSAT and PANAMSAT.

Alternate transponder channel spectra are allowed to overlap symmetrically and are provided with alternate polarization. The number of transponders in the satellite are effectively doubled by this process. Polarization discrimination can also provide a certain degree of interface isolation between satellite networks if the nearest satellite (in terms of angular orbit separation) uses orthogonal uplink and downlink polarizations. For linear polarization, discrimination between received horizontal and vertical fields can be as high as 50 dB but requires a polarization-sensing servo loop to maintain optimum discrimination. Circularly polarized fields such as those used on the DSCS and TDRS satellites do not provide much more than 30 dB discrimination, but they tend to be more stable and do not require polarity tracking [Ref. 6:p. 481]. The polarization method required for the array will be determined by the communication satellite system that is utilized for the data link.

VI. SATELLITE CONSIDERATIONS

A. COMMUNICATION SATELLITE INTRODUCTION

The requirements of the proposed system dictate a high capacity data transmission link with near-global coverage. The only current means of achieving this is with the use of communication satellites. There are many communication satellite systems in orbit today. This chapter will identify some of the systems capable of high data rate communications with mobile platforms such as aircraft. Both military and commercially leased systems will be addressed.

The Military Satellite Communications (MILSATCOM) architecture refers to the overall structure of U.S. military satellite communications system. The current MILSATCOM architecture is the integration of individual sub-architectures into a program that satisfies Department of Defense requirements (see Figure 6.1).

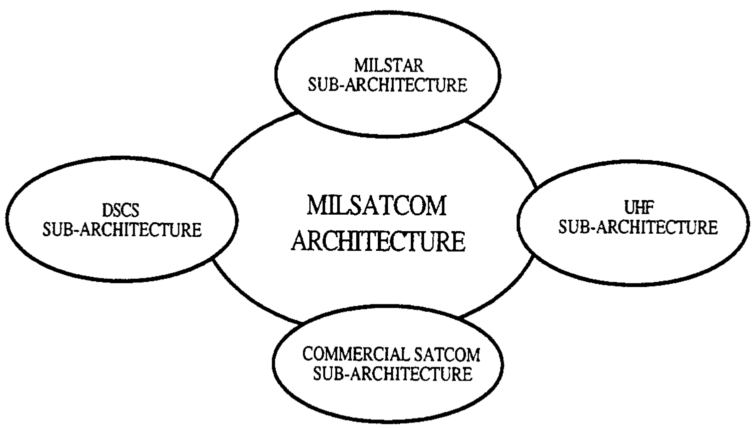


Figure 6.1 [Ref. 23:p. AR-6]

The success of commercial systems in the Desert Storm war has fed the notion that commercial and military systems are virtually functionally interchangeable for supporting DOD communications requirements. There are,however, several problems associated with the use of commercial band Fixed Satellite Service (FSS) by mobile users such as aircraft.

For instance, there are no International Telecommunications Union (ITU) allocations in the C- or Ku-bands for mobile use. This requires that mobiles use these bands on a non-interference basis with fixed sites or request clearance. In addition, Ku-band coverage is often limited geographically to high population land areas [Ref. 16:p. 1-4]. There are several advantages of commercial satellites, however, that may make leasing transponders an attractive option for many DOD applications. The advantages and disadvantages of both commercial and military satellite systems will be discussed in the following sections.

B. SATELLITE SYSTEM CHARACTERISTICS

The objective of this section is to describe satellite system characteristics that support the integration of particular systems into airborne high data rate communications requirements. These characteristics can be used to evaluate the strengths of competing systems for comparison purposes. There are several topics that will be discussed to describe the various types of satellite systems:

- Satellite services available to the user
- Geographic coverage
- Frequency bands/ Data rates

1. Satellite Services

In determining if a satellite system will be of use to our specific application, the type of service required for the application must be determined. Whether a service is supported by a satellite system is dependent upon the purpose and the intended use of the satellite, the particular satellite system operation, and the channel characteristics. Some satellites have been designed to simply support voice communications. In this case, service is limited and might not meet the requirements of high data rate applications. On the other hand, some satellite systems offer a broad range of services [Ref. 16:p. 2-9]. The type of services provided by communication satellites are dependent upon a receiver-transmitter combination called a transponder.

a. General Service Types

There are two basic categories of communications satellites. The first is a repeater satellite, commonly called the "bent pipe" satellite. The bent pipe satellite is basically a frequency translating RF repeater. The second type is the processing satellite, which is used exclusively on digital circuits, where at a minimum, the satellite demodulates the uplink signal to baseband and regenerates that signal for downlink.

Whereas analog circuits are exclusively bent pipe techniques, digital circuits may use either variety. Currently, most of the communications satellites in operation do not perform processing on the received modulated signals and operate in the repeater mode. The only procedure that is performed then is the translation between the uplink and the downlink frequencies. Operation of a transponder in this repeater mode allows for a broader selection of modulation techniques and access modes allowing greater flexibility for link design.

The most basic form of processing satellites is the implementation of on-board regenerative repeaters. This requires only that the uplink signal be demodulated back to the baseband signal and passed through a hard limiter or a decision circuit before regenerating the signal at the downlink frequency. There are several advantages to this processing:

- Isolation of the uplink and downlink by on-board regeneration prevents the accumulation of thermal noise and interference.
- Isolating the uplink and downlink makes the optimization of each link possible. For example, the modulation format of the downlink need not be the same as that for the uplink.
- Regeneration at the satellite makes it possible to implement various kinds of signal processing on board the satellite. This can add to the communication capacity of the satellite and provide a more versatile set of conveniences for the user network [Ref. 23:p. 408].

The processing of a received signal on board a satellite can improve the retransmitted signal, however the flexibility in using a repeater satellite is sacrificed in order to improve the transmission quality from the satellite. The implementation of signal processing systems aboard satellites has been limited in the past due to complexity, size, weight and reliability problems [Ref. 16:p. 2-10]. Military SHF and commercial Ku-band satellites do not, as of yet, incorporate processing but instead use wideband transponders.

b. Modulation and Multiple Access Protocols

Another aspect of communication satellite service is the type of multiple access and modulation techniques that the transponder can support. Multiple access techniques provide the ability for a number of users to simultaneously share the use of a satellite transponder. The common forms of multiple access techniques implemented are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). For FDMA, the multiple users are separated by frequency while in TDMA, they are separated by interleaving the signals in time. The CDMA technique uses spread spectrum transmissions with specific codes so that a transponder can be shared without interference from other users [Ref. 16:p. 2-7].

In order to adhere to a congressionally mandated program policy drafted by the Defense Support Project Office (DSPO), the proposed data link should be Common Data Link (CDL) compliant. The CDL standard dictates that the data link use TDMA access and specific data rates (see Chapter IV). For this reason only, TDMA-capable satellites will be addressed. The TDMA access technique is limited exclusively to digital operation.

c. Channels and Power

The bandwidth and power allotted for each channel and the number of channels available for use on the satellite may restrict support of a required service. For instance, if a satellite has only one channel, the availability and flexibility of that channel might be restrictive. In the case where more than one channel is available, an increase in flexibility and availability will result. An advantage of multiple channels is the ability to divide the uplink and downlink spectra among these channels. The division of the spectra through the use of multiple transponders significantly increases the power density that can be achieved on the downlink.

The bandwidth and power available in a satellite is limited. In addition to this limitation, the possible allocation of portions of these resources to multiple users might further restrict the availability of bandwidth and power. The utilization of the available transponder bandwidth and EIRP is dependent on the type of multiple access scheme implemented and the specific terminals in the link. A small terminal would require a larger fraction of satellite EIRP than bandwidth to complete the link, resulting in an inefficient use of satellite bandwidth. Therefore, the number of channels and amount of bandwidth and power available per channel might cause a satellite to be deemed inadequate for a specific application [Ref. 16:p. 2-10]. The large data rates involved in the transmission of motion video will push the available limits on both power and bandwidth.

2. Satellite Geographic Coverage

There are three basic types of satellite orbits:

- Polar
- Equatorial
- Inclined

Polar orbits are used typically for satellites that require synchronization with the sun, such as for photography. Inclined orbits produce a sinusoidal ground track over the earth's surface and are used for applications that typically require a low orbit but have limited time in view. The satellite orbits discussed in this study will be geostationary equatorial orbits. The geostationary orbit is a circular geosynchronous orbit that lies in the plane of the equator (0° latitude). A satellite in this type of orbit appears fixed over a point on the earth called the subsatellite point, which is given in longitude at the earth's equator. The satellite's range at this point, and only this point is 35,784 km [Ref. 6:p. 363]. The geostationary orbit is commonly used for communications satellites due to several benefits. Some advantages of geosynchronous satellites are the relative ease of tracking, negligible doppler shifts due to the satellite's motion, and continuous availability within each satellite's coverage zone. In order to provide coverage over the entire circumference of the earth's surface, a three-satellite constellation is required.

The primary disadvantages of geosynchronous satellites are that they cannot provide coverage at latitudes near the poles above approximately 70 degrees latitude, and also that of the long relay distances involved. Of particular importance to mobile users, the range loss, or free space loss of the transmitted and received signal strength is very large and often requires large antennas and higher power to compensate.

It should be pointed out here that geostationary satellites do have small residual relative motions. Over its subsatellite point, a geostationary satellite carries out a small apparent suborbit in the form of a figure eight because of higher space harmonics of the earth's gravitation and tidal forces from the sun and moon. The satellite also tends to drift off station because of the gravitational attraction of the sun and moon as well as solar winds [Ref. 6:p. 364]. Although these factors must be addressed when designing the link and antenna tracking system, the relatively large beamwidth resulting from the limited antenna aperture available on an aircraft will ease some of the pointing accuracy demands.

The P-3C is primarily a maritime patrol aircraft, therefore this video link system would require satellite availability over ocean regions. Recently emphasis has shifted in the Maritime Patrol Community from open ocean operations to those operations in the littoral, or coastal regions of the world. This realization will help ease the strict global coverage requirement due to the fact that most commercial satellites have their antennas pointed toward land masses for maximum revenue. Although military communications satellite systems offer near global coverage, there are several commercial systems that offer enough significant coastal and open ocean coverage to be useful to this application.

The types of antennas provided on a satellite determine the amount of earth coverage provided. The common coverage areas can be categorized by their 3 dB beamwidth often referred to as the half power beamwidth. These beamwidth areas are described as Earth coverage, area coverage, and spot beams [Ref. 16:p. 2-12]. Earth coverage has a beamwidth of approximately 17 degrees and has in its footprint all the line of sight area of the earth's surface (see Figure 6.2). Area coverage results from a beamwidth of approximately 5 to 8 degrees and typically covers an entire continent. Spot beams consist of beamwidths less than 5 degrees as shown in of Figure 6.2 (b).

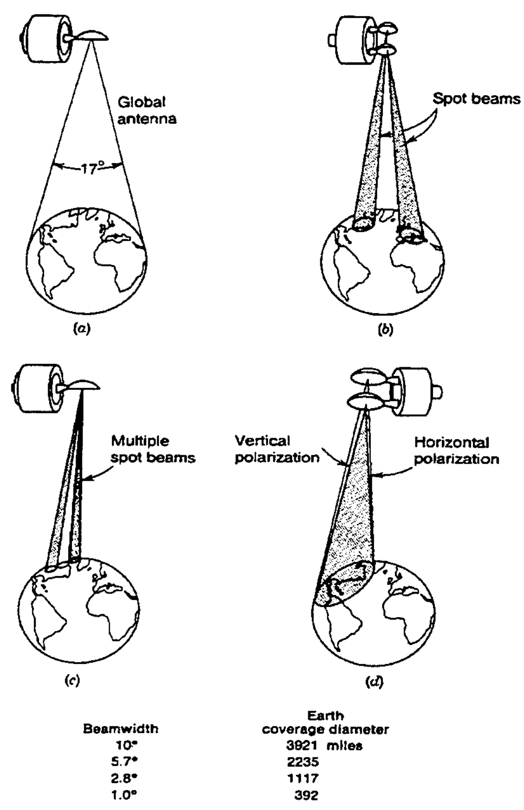


Figure 6.2: Typical Satellite Antenna Patterns and Coverage Zones [Ref. 23:p. IN-62]

The coverage provided by a satellite is dependent upon the design of the antennas which in turn is determined by the frequency and purpose of the satellite. Commercial satellites utilize fixed-shape beam antennas and are designed to produce a beam that corresponds to a single or composite geographic land mass. The antennas are often steerable, but would likely be very costly to accomplish. As discussed in Chapter V, the polarization employed in a satellite antenna must be known and be compatible with terminal operation due to frequency reuse plans as shown in Figure 6.2 (d). These characteristics of coverage must be identified for a system in order to determine the ability of a satellite system to support a specific application such as a highly mobile platform.

There exists a tradeoff for the satellite system between the achievable gain of the antenna and the coverage due to the beamwidth differences required between applications (see Table 6.1). A geosynchronous satellite that must transmit with global coverage will suffer a significant loss of gain that must be compensated for by power, or reduced data rate.

GAIN (dB)	19	20	24	27	30
BEAMWIDTH	18	16.4	10	7	5

Table 6.1: Gain - Beamwidth Relationships

3. Frequency Bands and Data Rates

a. Ultra High Frequency (UHF) Satellite Systems

The existing UHF constellation of Fleet Satellite (FLTSAT) and Leased Satellite (LEASAT) satellites offer reliable communications at a relatively low cost. The UHF systems are compatible with the TDMA standards required by the CDL, however the narrow bandwidths of the UHF channels limit the maximum data rates. The 25 KHz Demand Assigned Multiple Access (DAMA) standard supports data rates from 75 bps to 16

Kbps. This data rate is sufficient for still frame image transmission, but it is inadequate for full motion or even stop-motion video.

b. Super High Frequency (SHF) Satellite Systems

The SHF satellite system (often referred to by the IEEE designation of X-band) is characterized by the military Defense Satellite Communications System (DSCS). DSCS uses the 7900-8400 MHz band for the uplink and the 7225-7750 MHz band for the downlink. There is currently a constellation of five operational DSCS III satellites on orbit. The five satellites are referred to as ELANT, WLANT, EPAC, WPAC, and IO satellites reflecting the locations of the satellites. The five-satellite constellation provides global coverage excluding the polar regions.

Each DSCS III satellite has six wide-band channels. The satellite is channelized into six transponders of bandwidths varying from 50 MHz to 85 MHz. Two of the transponders are powered by 40 watt Traveling Wave Tube Amplifiers (TWTAs), and the other four transponders are powered by 10 watt TWTAs. Both the transmit and receive antenna systems have a combination of earth coverage horns and multi-beam antennas [Ref. 18:p. 14].

The data rates that are capable from DSCS satellites depend upon multiple factors such as channel selection and the percentage of available satellite power devoted to the application. The data link from a shore installation or ship to an aircraft will typically be satellite power limited. A sample DSCS data link computation was prepared by the MITRE corporation [Ref. 18: Appendix]. The link path was from a shore facility to a mobile platform that was equipped with a 1 square foot phased array antenna. The link used a 40 watt DSCS channel with a maximum satellite power application of 10 percent of available power. With the mobile terminal assuming to have a 300 watt power supply, the maximum possible data rate from the mobile platform to shore was approximately 100 Kbps. This rate was limited by the 300 watt power supply as less than 2 percent of the satellite transponder was required. The maximum data rate from the shore facility to the mobile platform was much less however. This reverse link was satellite power limited to less than 5 Kbps.

The technological requirements for this proposed system are significantly easier to satisfy for the forward link from the aircraft to the shore installation or ship. Because the aircraft is the platform generating the video, this allows us to concentrate on a forward simplex link that allows by far the greater data rates compared to the shore to platform link. If it becomes necessary for the aircraft to receive an image, a still frame could be sent with the lower data rate on the reverse link. By increasing the antenna size from one square foot to approximately 3 feet by 3 feet we can significantly increase the gain and perhaps the power to the antenna due to the increased heat dissipation area if using a phased array. These modifications would increase the data rate capability significantly.

DSCS provides wide coverage and has 500 MHz of bandwidth. It will become a standard communications medium for a large number of ships with the deployment of AN/WSC-6(V)XX terminals [Ref. 18:p. 17]. Utilizing DSCS will simplify the compatibility problems significantly by allowing reduced modifications to ship receivers.

c. Commercial (Ku-band) Satellite Systems

Part of the International Telecommunications Union (ITU) frequency allocation to the fixed satellite service is referred to as the Ku-band and encompasses 14.00-14.50 Ghz for the earth-to-space link and 10.95-12.75 Ghz for the space-to-earth link. Various Ku-band satellite systems have been implemented to provide domestic regional and global communications. Some satellites are implemented as Ku-band only systems and others as hybrid C- and Ku-band systems. Both International Telecommunications Satellite Consortium (INTELSAT) and Pan American Satellite (PANAMSAT) are global communications systems that use the hybrid C- and Ku-band satellites. Both INTELSAT and PANAMSAT lease transponder service, although the ability and cost to change spot beams locations may be prohibitive.

The major advantage of Ku-band fixed satellite service is that high power spot beams readily formed by the satellite allow the use of smaller antennas on the ground. The major disadvantage of using Ku-band is that the coverage is targeted at high population terrestrial regions throughout the world. Because of technology limitations, the commercial service suppliers cannot focus the radiated power as well as they would prefer (i.e., only on the desired land masses), and therefore significant Ku-band coverage exists in oceanic regions that fall in the periphery of operational areas [Ref. 18:p. 20].

The allowable data rates for a Ku band link are greater than that of an X-band for a given antenna size. As compared to the DSCS link mentioned earlier with a 1 square foot phased array antenna, a similar link budget was calculated for a 0.3 meter diameter phased array to an INTELSAT 701 satellite. The data rate from a mobile platform to shore was 1415.4 Kbps and increased to 5676.5 Mbps utilizing a 0.6 meter diameter phased array [Ref. 18: Appendix A-B]. These data rates are sufficient for motion video transmission (see Chapter IV).

d. Extremely High Frequency (EHF) Satellite Systems

The Milstar satellite program is designed to provide highly-survivable, jam-resistant satellite communications to mobile users in both strategic and tactical environments. Milstar operates in the uplink extremely high frequency (EHF) band of 43.5-45.5 Ghz and the downlink SHF band of 20.2-21.2 Ghz. The first two Milstar satellites, to be launched by 1995, offer a Low Data Rate (LDR) capability of 75 to 2400 bps which is too low for this application. A second generation satellite, Milstar II (which is planned for launch beginning in 1998) will offer a Medium Data Rate (MDR) capability up to 1.544 Mbps. Because the current capability is not adequate for the needs of this system, Milstar satellites will not be considered for use.

C. FEASIBLE SATELLITE SYSTEMS

The U.S. Congress has mandated a review of the MILSATCOM architecture with direction to consider the use of commercial systems [Ref. 16:p. 4-9]. The United States has implemented a concept of separating military and civil SATCOM. Consequently, there exist both dedicated military systems and systems nominally dedicated to civil or non-military users. The non-military systems are termed commercial systems irrespective of whether they are international, national, or regional in character.

Commercial systems are characterized by entrepreneurial activity, and hence competition and cost-effectiveness. It is, in fact, the concern for cost that motivates critics and congress to direct use of commercial SATCOM by U.S. military services. This concern is well placed; however, it would be simplistic and one dimensional to assume that commercial systems can be substituted for military sytems and that the result will be lower cost with little or no loss of critical performance. The issues are, in fact, complex and multi-dimensional, and will require a significant evaluation that must necessarily take place over an extended period [Ref. 16:p. 4-9].

In contrast to commercial systems, the emphasis of military systems is on hardening of satellites against nuclear effects, anti-jam resistance, low probability of signal intercept and global coverage (see Table 6.2). Commercial systems stress cost-effectivesness, low cost user equipment, and access through numerous facilities. Since military use would be small in comparison to overall markets, it is unlikely that military customers could influence either allocation of current resources or evolution of design [Ref. 16:p. 4.9].

Balancing the requirements for high data rates, transponder availability, and ocean coverage, three satellite systems that best balance these needs are selected for further discussion. These systems are DSCS III, INTELSAT and PANAMSAT.

	MILSAT	COMMERCIAL SATCOM
COVERAGE	WORLDWIDE (POLAR)	GENERALLY REGIONAL
ORBIT	GEOSTATIONARY &	GEOSTATIONARY
ORBIT UTILIZATION	LOW	HIGH
SPECTRUM USE	LOW	HIGH
CAPACITY	LOW & HIGH DATA RATE	HIGH DATA RATE
TERMINALS	SMALL & LARGE	SMALL & LARGE
GRADE OF SERVICE	FAIR	HIGH (TOLL QUALITY)
RELIABILITY	DEPENDS ON ALTERNATIVE	HIGH (ON-ORBIT SPARES)
SECURITY	MANDATORY	DESIRABLE
ANTI-JAM	HIGHLY DESIRABLE	NOT REQUIRED
PHYSICAL SURVIVAL	DESIRABLE	NOT REQUIRED

Table 6.2: MILSATCOM & Commercial SATCOM Feature Comparison

1. DSCS III

The DSCS III system is a set of five operational, X-band transponding satellites all in geostationary orbit. In addition to Earth coverage horns, the DSCS III satellites each have one 61-element receive multi-beam antenna (MBA) and two 19-element transmit MBAs. Each MBA has a single beam forming network (BFN). The two transmit MBAs are each available to separate pairs of transponder channels. A single transmit gimballed dish antenna (GDA) is also available that produces a steerable spot beam of higher EIRP. Some specific performance capabilities to be used in link calculations are listed in Table 6.3.

	EIRP	G/T
GDA	44 dBW	
MBA	23 to 40 dBW	-1 to -16 dB/K
Horn	25 dBW	-14 dB/K

Table 6.3: DSCS III Performance Capabilities [Ref. 16:p. 2-16]

The primary advantages of utilizing DSCS are its worldwide coverage spanning ocean areas and its compatability with a large number of ships and military facilities. The five-satellite DSCS constellation provides global coverage permitting connectivity to nearly all forseeable regions of interest (see Figure 6.3).

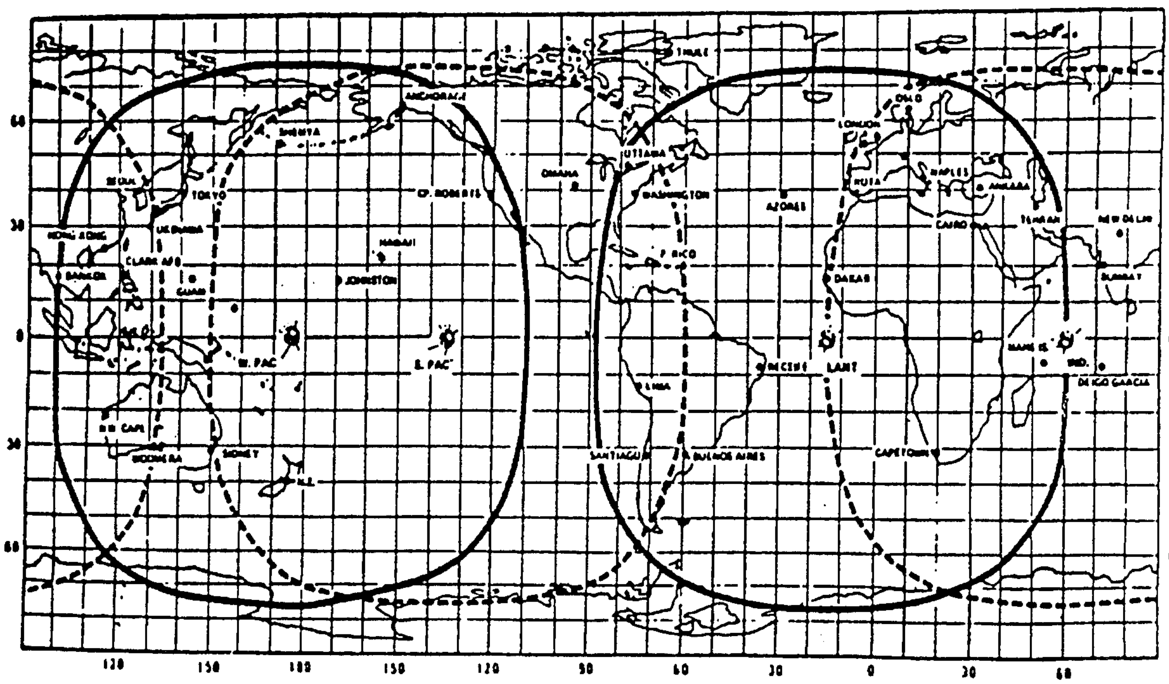


Figure 6.3: DSCS Geographic Coverage [Ref. 24]

The primary disadvantage of DSCS is the large number of other DOD users that are competing for DSCS resources such as antenna coverage for spot beams and transponder allocation. The ability to utilize a simplex link from the aircraft to the ground facility will simplify the availability problem somewhat. In addition the planned upgrade to the Demand Assigned Multiple Access (DAMA) protocol will make more efficient use of the available resources.

The DSCS satellites have the capability of satisfying the system requirments if sufficient transponder allocation can be obtained. The maritime patrol communicty may have to conform to time-slot availabilities until the DAMA protocols become available.

Provided that the communicty can get the necessary resources, the advantages of large coverage areas, DOD control and robustness make the DSCS satellites an attractive option.

2. INTELSAT

The International Telecommunication Satellite (INTELSAT) consortium is an international organization with numerous member nations. Originally intended to provide transoceanic communication services, INTELSAT now also provides domestic network connectivities. The performance of the INTELSAT transponders is a function of the antenna type connected to the transponder along with the transponder bandwidth. The series INTELSAT II, III, and IV/IVA have dropped out of service for the larger capacity and more robust INTELSAT V, VI, and VII. There are many INTELSAT satellites currently on orbit spanning the earth (see Table 6.4).

Orbital Location	1993	1994	1995	1996
Indian Ocean & Asian Land Regions				
57.0 E	507	512	512	512
60.0 E	602	602	602	604
63.0 E	604	604	504	602
66.0 E	505	704	704	803
91.5 E	501	501	501	-
95.0 E	-	-	-	-
Pacific Ocean Region				
174 E	701	701	701	801
177 E		702	702	802
180 E	508	706	706	701
177 W	511	511	511	510

Orbital Location	1993	1994	1995	1996
Atlantic Ocean Region				
56.0 W	-	-	513	513
53.0 W	513	703	703	706
50.0 W	506	506	506	515
40.5 W	510	510	705	708
34.5 W	603	603	603	603
27.5 W	601	601	601	601
24.5 W	605	605	605	605
21.5 W	502	502	502	502
21.5 W	K	K	K	K
18.0 W	515	515	515	707

Table 6.4: INTELSAT Satellite Numbers and Locations [Ref. 24]

The services provided by INTELSAT has traditionally been FDMA multiplexed voice channels and television-using large antennas. There is growing use of TDMA to increase capacity. Beginning with the INTELSAT VI series, there exists TDMA capability in which the satellite reconfigures antenna beam characteristics between TDMA bursts. In addition, the INTELSAT VII satellites will include multiple higher power Ku-band transmitters (to 50 watts) to facilitate the use of smaller terminals [Ref. 16:p. 2-18]. This section will emphasize the INTELSAT VII series for specific performance discussion.

The INTELSAT VII is a hybrid C- and Ku-band satellite. The C-band coverages are much broader than the Ku-band areas which are spot coverages. Figure 6.4 is a representation of coverage from and INTELSAT VII satellite. Spot beams 1, 2, and 3 are the coverage areas of the Ku-band. These beams may be pointed in other directions. The other zones are the coverage areas of the satellite's C-band transponders. The narrower Ku-band coverage areas are the result of the service performance required due to higher system noise temperatures and the added impact of rain at the Ku-band. The increased satellite gain from narrowing the coverage areas compensates for these factors.

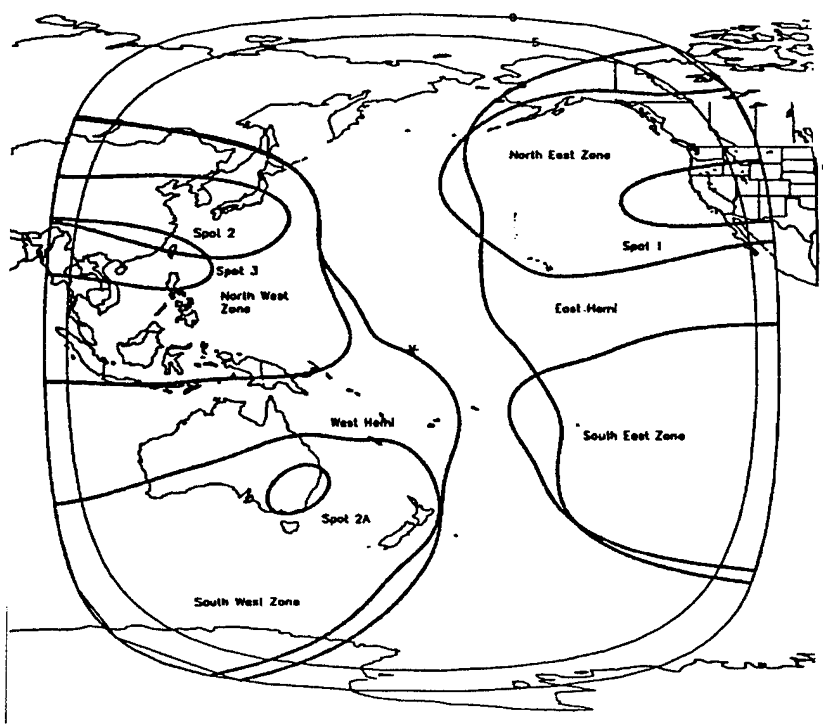


Figure 6.4: Sample INTELSAT coverage zones [Ref. 23:p.CS-17]

The specified minimum Effective Radiated Power (ERP) varies between 41 and 46 dBW at the outer coverage zones of the spot beams depending upon the specific band. The ERP varies rapidly when getting close to the outer contour so performance will degrade when flying near the contours. A full transponder for one-way (simplex) communication would cost approximately $311,000 per month on a five year lease basis, if access to it is arranged with Communication Satellite Corporation (COMSAT), based on COMSAT's current tariff. Leases on a 1 year and 10 year basis would increase or reduce the monthly costs to $386,730 and $275,000 respectively [Ref. 18:p. 25]. It is not known if these costs can be shared with other DOD agencies as this system will likely be used intermittently.

A representative data rate transfer versus antenna diameter chart was generated by the MITRE corporation concerning communication between a submarine and shore facility using an INTELSAT 701 satellite (see Figure 6.5). The INTELSAT 701 is located at 186

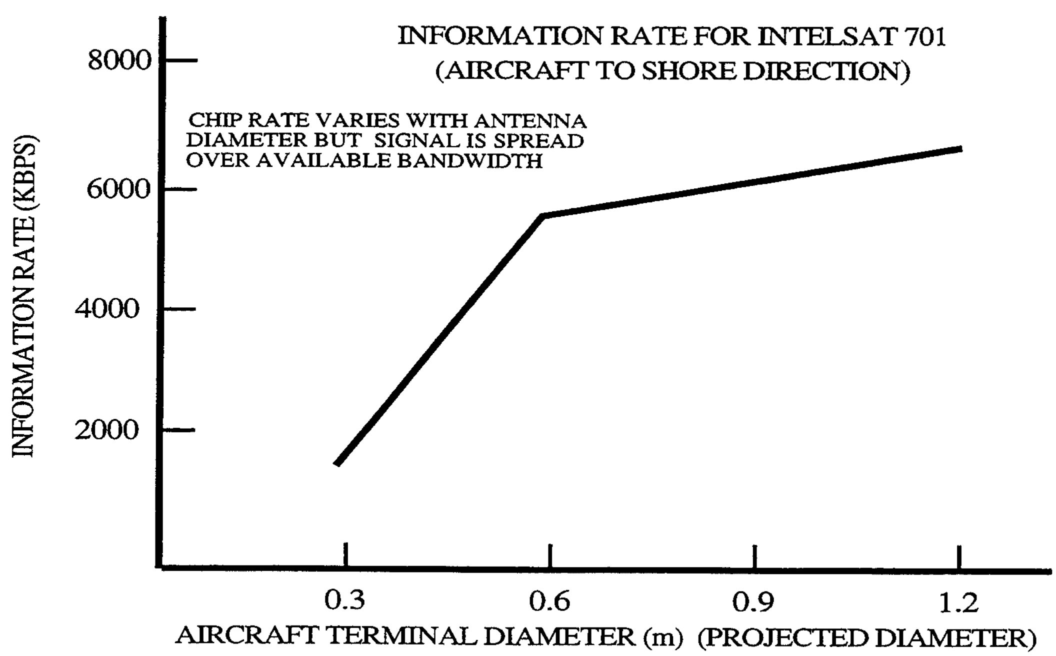


Figure 6.5 [Ref. 18:p. 25]

degrees west longitude. The assumptions are that the antenna on the mobile platform has a +/- 1 degree pointing error for all antenna sizes and that the power is limited to 1 Kw. If the aircraft transmitter cannot support the radio frequency (RF) power required, a proportional reduction in the information rates will be necessary. For example, if the aircraft transmitter size is limited to about 0.5 Kw, the information rates will be reduced to approximately one-half of those shown. [Ref. 18:p. 27]

The results of the MITRE study revealed that the percent of the available transponder power required for the forward link is very small, less than one to several percent of the full useful power [Ref. 18]. However, the full transponder bandwidth would have to be available to accommodate the spread spectrum signal. The signal was spread due to limitations that are expected for off-boresight transmissions to avoid potential adjacent satellite interference.

The information rates could be increased by a factor of two if the aircraft operates near the maximum ERP point of Figure 6.8, or decreased by a factor of two if operating near the outer contours. So there is a clear coverage "cost" if a doubling of the information rates is desired. The communications performance decreases rapidly as the aircraft attempts to operate near and beyond the outer contours [Ref. 18:p. 26].

The INTELSAT system provides a viable alternative to meet the communication needs of the P-3C video link. The advantages of the INTELSAT option is that of a large data capacity, many available satellites, and the ability to pay as you go. The primary disadvantages of the system are the potential interference issues with neighboring satellites, limited oceanic coverage, and power losses due to the linear polarization limitation.

3. PANAMSAT

The Pan American Satellie (PANAMSAT) corporation is the first private international satellite company and is headquartered in Greenwich, CT. At present PANAMSAT operates two satellites (PAS-1 and PAS-2) located at 45° W and 169° E longitude. PAS-1 provides Ku-band coverage of the United States and Europe with spot beams, and PAS-2 provides Pacific service. Additional satellites, PAS-3,4,5 are planned to add coverage to Africa and Pacific regions.

PANAMSAT has technical performance and connectivity parameters similar to the INTELSAT Ku-band parameters [Ref. 18:p. 29], and there is no reason to expect that communication performance via PANAMSAT would be substantially different than with INTELSAT 701. Detailed cost of transponder lease was not available but is probably similar to INTELSAT fees. Use of PANAMSAT by the U.S. military would have to address the issue of interference with INTELSAT, since the United States is a member of that coalition and a waiver might be required [Ref. 16:p. 2-19].

VII. LINK BUDGET ANALYSIS

A. LINK BUDGET INTRODUCTION

The link budget is a tabular method of calculating space communication system parameters. The link budgets in this chapter are not intended as precise engineering design computations but rather as estimates of system capabilities. Due to incomplete information on PANAMSAT performance figures only INTELSAT VII and DSCS III systems will be tabulated. The difference in capabilities between PANAMSAT and INTELSAT is relatively small, however, and we will assume that they are comparable. Before tabulating the link budgets, a brief description of performance parameters is required.

To understand link design, we need to define the relationship between data rate, antenna size, propagation path length, and transmitter power. This relationship is defined by a link equation which relates all of the parameters needed to compute the signal-to-noise ratio of the communications system. The basic equation used in sizing a digital data link is [Ref. 19:p. 520]

$$\frac{E_b}{N_o} = \frac{P L_l G_t L_s L_a G_r}{k T_s R} \quad ,$$

where E_b/N_o is the ratio of the received energy-per-bit to noise density, P is the transmitter power, L_l is the transmitter-to-antenna line loss, G_t is the transmit antenna gain, L_s is the free space loss, L_a is the transmission path loss, G_r is the receive antenna gain, k is the Boltzmann's constant, T_s is the system noise temperature, and R is the data rate. The propagation path length between transmitter and receiver determines L_s, where L_a is the function of factors such as pointing losses and rainfall loss.

In digital communications, the received energy per bit, E_b, is equal to the received power times the bit duration. The noise power at the receiver input usually has a uniform noise spectral density, N_o, in the frequency band containing the signal. It is the ratio of E_b/N_o that will eventually determine how much information we can transmit over the data link.

It is more convenient to perform link calculations in decibels, or dB. This allows us to add or subtract the parameters rather than multiply or divide. The gain or loss of an element in the link budget is expressed as the ratio of output to input power, P_o/P_i. A decibel is defined as $10\log_{10}(P_o/P_i)$, where P_i is the input power to an element such as the antenna and P_o is its output power. A loss in decibels is a negative number. The above equation can be written in decibels as

$$E_b/N_o=EIRP+L_s+L_a+G_r/T_s+228.6-10\log R$$

where EIRP is in dBW, L_s, L_a are in dB, the sensitivity of the receiving station, G_r/T_s, is expressed in dB/K, $10\log k=-228.6$ dBW/(Hz-K), and R is in bps.

The bit rate required for full motion video with existing compression technology is 3 Mbps. This data rate complies with the CDL compatibility requirements (see Chapter IV). In order to protect the quality of the compressed video, a Bit Error Rate (BER) of 10^{-9} is desired. This means that on the average, only one bit will be in error for every 10^9 bits received. It is the BER, which is a function of E_b/N_o, that is used to evaluate the performance of the link. The use of Forward Error Correction (FEC) algorithms can significantly reduce the E_b/N_o requirement which in turn reduces the required transmitter power and antenna size, or increases the link margin. Using the Reed-Solomon forward error correction method discussed in Chapter IV, the BER requirement will be met at an E_b/N_o of approximately 4.6 dB (see Figure 7.1).

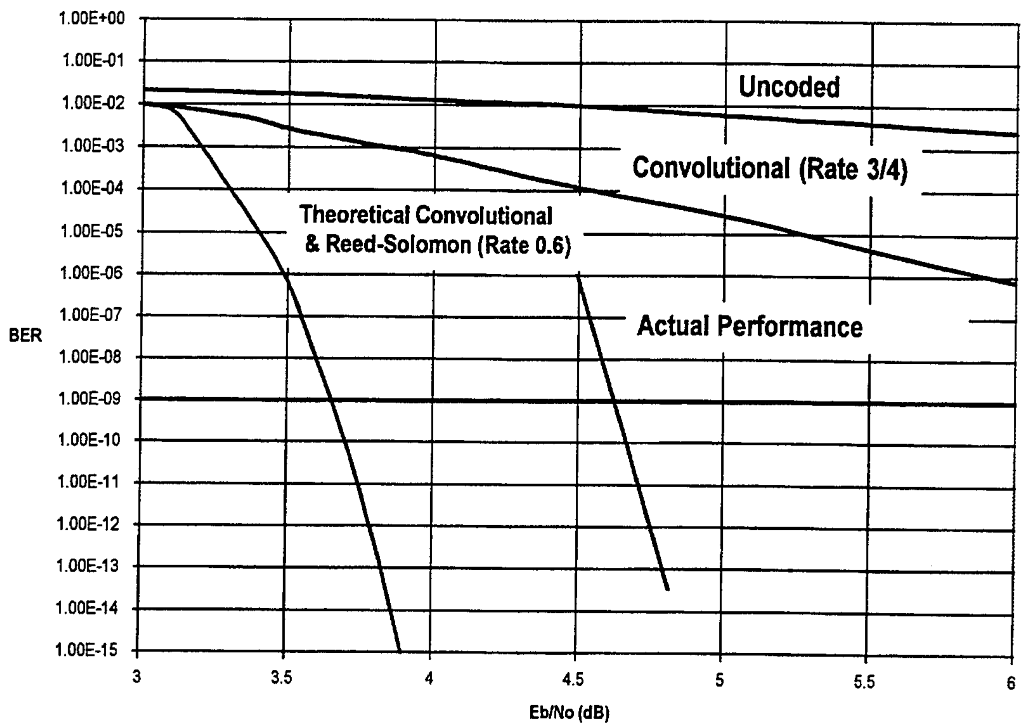


Figure 7.1: BER Performance [Ref. 24]

B. DSCS III LINK BUDGET

The sample power link budget for the DSCS III satellite will involve several assumptions. The first assumptions are that the P-3C transmitting antenna has a radiated power of at least 50 dBW, the aircraft is located in a spot beam from the satellite's multi-beam antenna, and that the P-3C is the sole user of the transponder. In addition, the ground receiving station is to be equipped with a 6 foot diameter parabolic antenna. Both the P-3C and the receiving station are assumed to be located at the same geographic latitude of approximately 40 degrees, but each will differ from the satellite's longitude by 40 degrees to simulate a long distance link.

The link computations will be divided into two parts, the uplink (see Table 7.1), and the downlink (see Table 7.2). The transmission path losses will consist of generally

UPLINK	
P-3C EIRP	+50.0 dBW
Transmit Antenna Pointing Loss	-0.5 dB
Free Space Loss (at 8 GHz)	-202.2 dB
Atmospheric Attenuation	-0.5 dB
Rain Attenuation	-1.0 dB
Polarization Loss	-0.5 dB
Boltzmann's Constant	+228.6 dBW
Bit Rate (at 3 Mbps)	-64.8 dB-Hz
Receive Antenna Pointing Loss	0.0 dB
Receive Antenna G/T	-1.0 dB/K
Link Energy per Bit/ Noise Density	8.1 dB

Table 7.1: DSCS III Uplink Power Budget

DOWNLINK	
DSCS III EIRP	+40.0 dBW
Transmit Antenna Pointing Loss	-0.5 dB
Free Space Loss (at 7.3 GHz)	-201.4 dB
Atmospheric Attenuation	-0.5 dB
Rain Attenuation	-1.0 dB
Polarization Loss	-0.5 dB
Boltzmann's Constant	+228.6 dBW
Bit Rate (at 3 Mbps)	-64.8 dB-Hz
Receive Antenna Pointing Loss	-0.5 dB
Receive Antenna G/T	18.0 dB
Link Energy per Bit/ Noise Density	17.4 dB

Table 7.2: DSCS III Downlink Power Budget

accepted default values for atmospheric and rain attenuation, polarization loss and antenna pointing loss. The resulting tabulated E_b/N_o for the uplink is 8.1 dB, and for the downlink it is 17.4 dB. The E_b/N_0 for the combined link is 7.6 dB which provides a 3.0 dB link margin above the 4.6 dB minimum required to maintain the desired BER.

The power requirement of 50 dBW from the P-3C transmitting antenna is a minimum requirement which can be increased to allow a larger link margin or a greater maximum aircraft roll angle. Reference 24, a Boeing Defense and Space Group briefing to NAVAIR, estimated that the 50 dBW requirement could be met with a phased array antenna measuring approximately 16 inches by 16 inches in surface area, with a 1.5 inch thickness. This antenna would weigh 27 pounds and would consume approximately 640 watts of DC power.

C. INTELSAT VII LINK BUDGET

The power link budget for the INTELSAT VII satellite will include many of the same assumptions as that for DSCS III. The differences are that the minimum EIRP has increased to 60 dBW, primarily due to increased rain attenuation and polarization losses associated with the higher frequencies. The INTELSAT VII transmission is linearly polarized and the antenna on the P-3C will likely utilize circular polarization to avoid a polarization tracking requirement. This will result in a 3 dB polarization mismatch loss in the power budget for the uplink. The ground station receive antenna size will measure 6 feet in diameter with a G/T of approximately 18, although these parameters could be increased if needed. The 6 foot dish antenna size was utilized to give the system an on-board ship capability.

The link budget computations, similar to that of part B, are divided into the uplink and downlink. The uplink (see Table 7.3) has a tabulated E_b/N_0 value of 7.7 dB, and the downlink computations (see Table 7.4) result in an E_b/N_0 of 14.8 dB. The combined link E_b/N_0 value is 6.9 dB. This provides a margin of 2.3 dB over the required Eb/No in order to obtain a BER of 10^{-9}.

The greater EIRP power requirement to close the INTELSAT VII link necessitates the use of a larger transmitting antenna on the aircraft. Utilizing the phased array

UPLINK	
P-3C EIRP	+60.0 dBW
Transmit Antenna Pointing Loss	-0.5 dB
Free Space Loss (at 14 GHz)	-207.1 dB
Atmospheric Attenuation	-0.5 dB
Rain Attenuation	-5.0 dB
Polarization Loss	-3.0 dB
Boltzmann's Constant	+228.6 dBW
Bit Rate (at 3 Mbps)	-64.8 dB-Hz
Receive Antenna Pointing Loss	0.0 dB
Receive Antenna G/T	0.0 dB
Link Energy per Bit/ Noise Density	7.7 dB

Table 7.3: INTELSAT VII Uplink Power Budget

DOWNLINK	
INTELSAT VII EIRP	+45.0 dBW
Transmit Antenna Pointing Loss	-0.5 dB
Free Space Loss (at 11 GHz)	-205.0 dB
Atmospheric Attenuation	-0.5 dB
Rain Attenuation	-5.0 dB
Polarization Loss	-0.5 dB
Boltzmann's Constant	+228.6 dBW
Bit Rate (at 3 Mbps)	-64.8 dB-Hz
Receive Antenna Pointing Loss	-0.5 dB
Receive Antenna G/T	18.0 dB
Link Energy per Bit/ Noise Density	14.8 dB

Table 7.4: INTELSAT VII Downlink Power Budget

technology described in part B, the antenna would measure approximately 24 inches by 24 inches by 1.5 inches. This antenna would consume 2000 watts of DC power and weigh 40 pounds.

D. LINK BUDGET SUMMARY

The sample link budgets of the DSCS III and INTELSAT VII demonstrate that the power requirements of the link can be met provided that adequate satellite resources are available. There are several variables that can be modified to improve the characteristics of the link. These include increasing the power to the aircraft's transmitting antenna, improving the gain of the aircraft antenna, and utilizing a larger aperture ground station antenna. These alterations would provide a greater link margin or allow a decrease in satellite resource allocation. If the satellite bandwidth and power are available, the proposed link can be completed.

VIII. USER INTERFACE AND IMAGE DISSEMINATION

A. OVERVIEW

Assuming the communications link is feasible and the transmitted images reach their respective destinations (i.e., ground stations), the remaining issues deal with how the received images can be exploited and then further disseminated for tactical use. These issues will be addressed with the assumption that the proposed CDL compliant link also includes a video compression system comparable to the Model SVC-3 discussed in Chapter IV. This chapter will discuss how the users, both airborne operators and shore personnel, interface with the proposed system, and the procedures for incorporating the images into the Joint Maritime Command Information System (JMCIS) for tactical dissemination.

B. USER INTERFACE

There are two opportunities for user interface during the communications link: onboard the aircraft and at the receiving station. The airborne operator determines image quality through the use of several parameters (horizontal resolution, quantization level, etc.), while keeping the frame rate constant. Ground station personnel analyze received images and ensure image dissemination.

1. Airborne Operator Interface

Since the airborne operator has direct access to the imaging system, image exploitation must occur onboard the aircraft prior to data transmission. Once the video signal enters the SVC-3, the operator can manipulate the image via an RS-232 terminal interface. As discussed previously, the SVC-3 transmits at a constant data rate meeting link requirements. However, the operator has the ability to adjust several parameters (see Chapter IV), which enable image manipulation. These parameters can be altered with the main tradeoff being a reduction in frame rate (i.e., less than full-motion). This reduction in frame rate results in the visual image appearing as a "still-frame" for frame rates less than 2.5 frames/second and "jerky-motion" for frame rates greater than 2.5 frames/second.

The type of communications link (simplex, duplex, or full-duplex) designed is a major factor in determining how much interface the airborne operator should have. With a full-duplex or duplex link, an onstation P-3C would be capable of receiving tasking updates via CDL from a controlling unit (i.e., TSC or surface ship) desiring increased resolution of a received image. With a simplex (one-way aircraft to ground) link, tasking updates would need to be conducted over existing voice channels (HF, UHF, etc.). The unreliability of secure voice communications in a tactical environment is well documented; HF frequencies are environmentally dependent and UHF circuits are typically overcrowded. Therefore, with a simplex link, it would be advantageous for the image manipulation to occur at the ground station. Unfortunately, ground station personnel are limited to the quality of the received image (i.e., an image can not be enhanced to a better resolution than it was received).

2. Ground Station Personnel Interface

Whether the images are received at a shore installation, such as a TSC, or onboard ship, the image retrieval process is identical. The received constant data rate signal is processed by the CDL Surface Communications Element (SCE) and fed into an SVC-3 compatible video compression decoder system. The decoder accepts the digital video signal from the communications link devices and converts it back into the original standard analog (RS-170, NTSC, etc.) signal suitable for viewing, recording, or transmitting.

All of Enerdyne's video compression decoder systems include an alphanumeric overlay function [Ref. 14]. With this capability, ground station personnel can annotate received images, highlighting specific areas of interest. Once the images are analyzed and the overlay function is completed, ground station personnel can disseminate the images by incorporating them into the imagery segments of JMCIS.

C. IMAGERY DISSEMINATION THROUGH JMCIS

JMCIS is an automated C4I system with interfaces to a variety of military communications and computer systems, including all U.S. Navy aircraft carriers and eventually, all overseas Tactical Support Centers (TSCs). JMCIS is designed to meet the unique tactical situation assessment, data fusion, and display needs of battle group and force commanders, subordinate warfare commanders, ship commanding officers, and shore command centers. The JMCIS concept evolved as a result of various C4I initiatives and culminated with the development of a command and control system in which specific applications are built on top of a "superset" of core software. The core software includes track database management, communications interfaces, message processing, track correlation, relational database management, and tactical display capabilities. Specific applications, such as the Imagery Segments, are built on top of the core system [Ref. 25].

The Imagery Segments are designed to provide tools for the Imagery Analyst to capture, exploit, store, print and disseminate images. Listed below are all the Imagery Segments (see Figure 8.1) along with a brief description of each [Ref. 26]:

- National Imagery Transmission Format (**NITF**) Services
    - Supplies the tools necessary to process NITF messages
        - message parsing into database
        - valid NITF file formatting
        - address, edit, create and delete message elements
- Digital Product Server (**DPS**)
    - Provides archiving, cataloging and retrieval of digital imagery products.
    - Provides a client interface to other segments which allow data entry, catalog query/selection and data retrieval.
    - Provides file format translation and data backup/restore.
- Imagery Acquisition Module (**IAM**)
    - Provides the ability to capture images from a Howtek or Vexcel scanner, analog video sources, or from several different types of cameras.

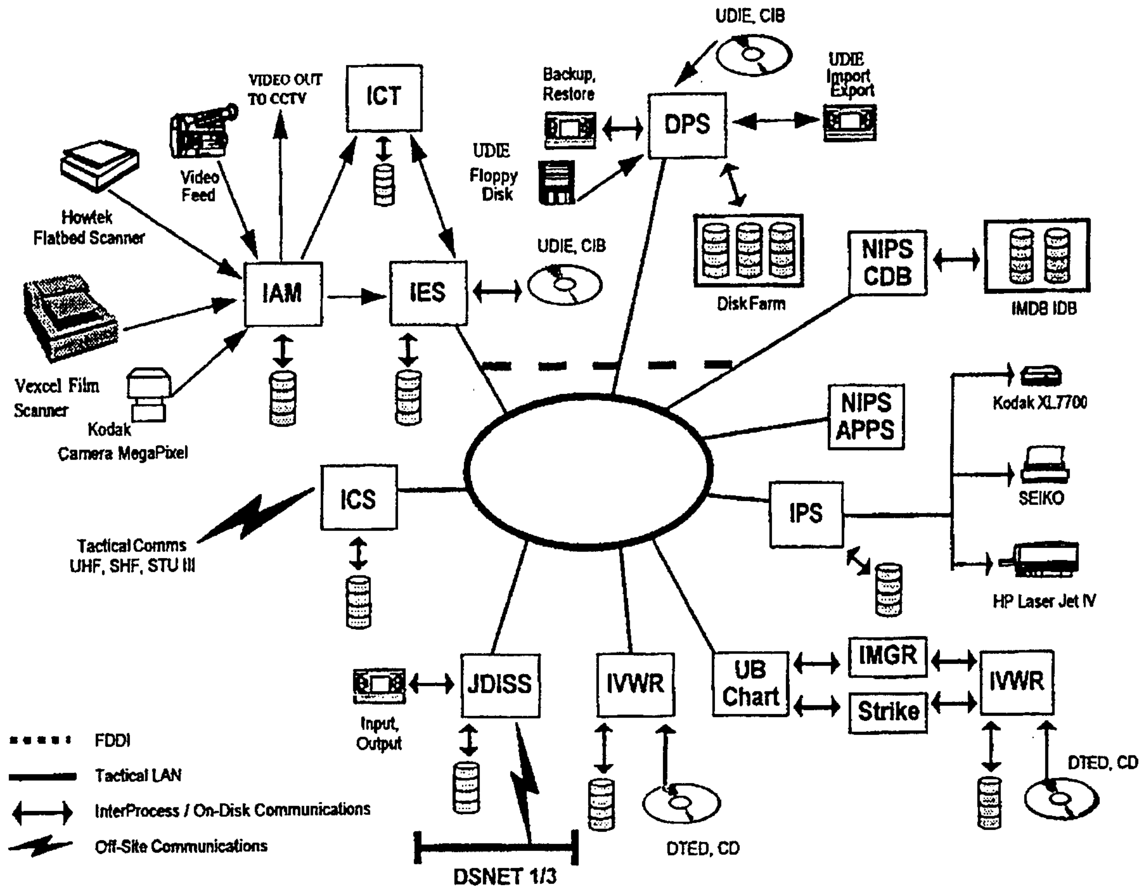


Figure 8.1: JMCIS Imagery Architecture [Ref. 26]

- Image Composition Tool (**ICT**)

  - Provides the ability to display imagery from a file system or DPS and to build an NITF image with annotations, graphic symbols, and sub images and store the image.

- Image Exploitation Services (**IES**)

  - Provides the analyst the ability to exploit the images with enhancements, annotations, mensuration, and registration

- Imagery Communication Services (**ICS**)

  - Provides users with the tools to send and receive digital imagery through available tactical and strategic communication channels (UHF, SHF, STUIII).

- Joint Deployable Intelligence Support System (**JDISS**)
    - Provides the capability for imagery manipulation/exchange through access to the Defense Secure Network (DSNET)-1 (GENSER SECRET) and DSNET-3 (SCI).
- Imagery Print Services (**IPS**)
    - Provides the ability to print images to several printers (Kodak, Seiko, and Laser Jet).
- Image Viewer (**IVWR**)
    - Provides the ability to "view only" the images in DPS.
- Image Manager (**IMGR**)
    - Provides the ability to plot image footprints on the system Chart.

Once the images are received by the ground station, they can be incorporated into JMCIS through the use of the Imagery Acquisition Module (IAM). The image transmission systems that are currently in use utilize JDISS for imagery dissemination (see Appendix). With the proposed system, ground station personnel have several options for entering the images into JMCIS. Images can be fed directly from serial port to serial port in the form of analog video, or still-frame images can either be scanned in or entered via a digital snapshot. Once the image is incorporated into JMCIS, anyone with access to the system and in possession of the appropriate Imagery Segments has access to the inputed image (see Figure 8.1).

IX. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The goal of this thesis was to address the feasibility of a system capable of transmitting full-motion video from the P-3C to ground stations beyond line-of-sight. This was accomplished by examining the flow of data from the video source to the ultimate destinations and identifying probable areas of concern. As mentioned throughout the thesis, full-motion video equates to extremely large bandwidth. By investigating how the proposed system could handle bandwidth of this size, two technological areas of concern became apparent: antenna and video data compression technology.

The driving factor in closing the power link budget is meeting the transmitting aircraft's EIRP requirement. In order to satisfy this requirement, the P-3C aircraft requires the installation of an additional antenna, either a reflector or phased array (see Chapter V). The technological functionality of both of these types of antennas is already proven in the commercial marketplace and is comparable to each other.

The computations of the link budget analyses (see Chapter VII) are based on the assumption that the transmitted data rate is approximately 3 Mbps (2T1). To achieve this data rate and also remain CDL compliant, the rate of the data entering the CDL Platform Communications Element must be 1.544 Mbps (T1), due to the CDL FEC encoding (rate 1/2) [Ref. 8:p. 43]. Existing video compression technology must be incorporated into the proposed system in order to reduce full-motion video to the size of a T1 data rate. Further investigation is required to ensure CDL compliance is maintained after including a video data compression system, such as LORAL-MICROCOM's SVC-3, into the proposed system. Figure 9.1 is a block diagram of the airborne portion of the proposed system.

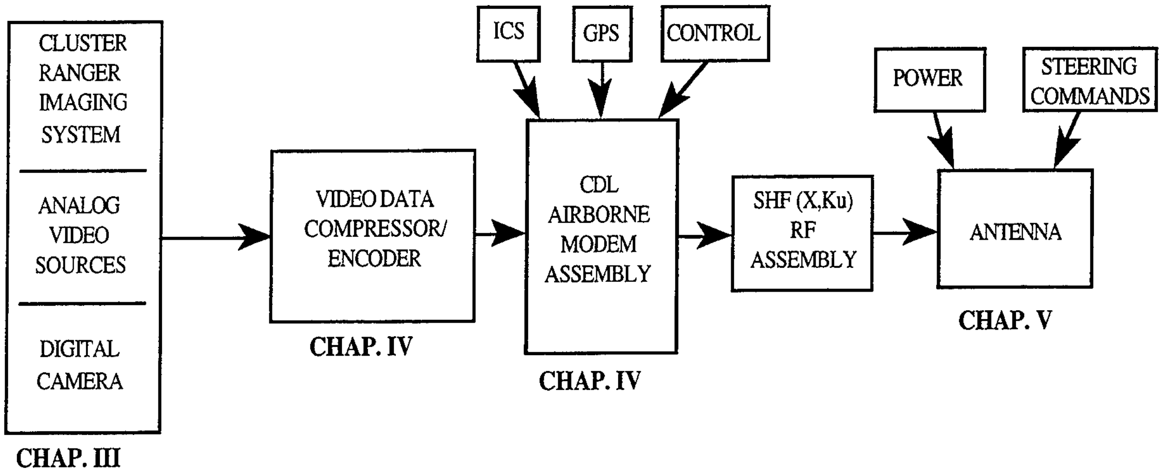


Figure 9.1: Proposed Block Diagram

B. RECOMMENDATIONS

There exists a need for a detailed requirements analysis specifying the minimum acceptable frame rate reception by the tactical user. As previously mentioned (see Chapter IV), a decrease in frame rate may translate to an increased resolution capability, or comparable resolution at a decreased bandwidth. If the frame rate requirement decreases to one of still-frame transmission, existing onboard UHF SATCOM antennas and the Navy UHF SATCOM system can be utilized to meet the requirement.

Provided a valid requirement exists for motion video, a detailed cost and availability analysis comparing the use of military satellite architecture versus commercial satellite architecture is imperative. In addition to selecting the satellite architecture, the appropriate antenna configuration must be determined. A complete analysis including installation costs and relative performance must be performed prior to selection.

APPENDIX (U)

Due to its classified nature, this appendix can be found in the document entitled **Digital Video Transmission From The P-3C To Beyond Line-Of-Sight Destinations: APPENDIX.**

LIST OF REFERENCES

1. Maness, A., "Requirements for Maritime Patrol Forces," *ASW Log*, April 1992.

2. Brooks, R.E., "If It Was There, P-3s Found It," *Proceedings*, pp.41-43, August 1991.

3. Reade, D., "ASUW Improvement Program," *Airborne Log*, pp.37-39, September 1993.

4. Naval Air Warfare Center RECON/SURV Branch Code 5013 Report,, *Cluster Ranger Surveillance System,* by Fran Chamberlain, Program Manager Electro-Optics Sensor Program, 5 March 1992.

5. Freeman, Roger L., *Telecommunication Transmission Handbook,* Third Edition, John Wiley & Sons, Inc., 1991.

6. Haykin, Simon, *An Introduction to Analog and Digital Communications*, McMaster University, Wiley Publishing, 1989.

7. Secretaries of Military Departments Memorandum, Subject: CDL Policy, Assistant Secretary of Defense/C3I, 13 December 1991.

8. Airborne Reconnaissance Support Program Office (ARSPO), *A-Level System Specification for CDL Segment-Class I*, 20 January 1990.

9. Interview between Frank Yakos, UNISYS, Washington, D.C., and author, 20 February 1995.

10. Interview between Alice Hagarty, ADROIT Systems, Washington, D.C. and author, 13 July 1995.

11. SS3001 course handout, *Spread Spectrum*, Naval Postgraduate School, Monterey, California, December 1994.

12. LORAL-MICROCOM, *SVC-3 Secure Video Compression Product Overview*, 1994.

13. Rabbani, Majid, *Digital Image Compression Techniques*, SPIE-The International Society for Optical Engineering, 1991.

14. Interview between Gary Gillman, LORAL-MICROCOM, Warminster, Pa. and author, 10 July 1995.

15. Interview between Howard Eckstein, LORAL-MICROCOM, Warminster, Pa. and author, 5 July 1995.

16. MITRE Corporation, *Submarine Superhigh Frequency Satellite Communications Technology Interim Report*,by W.T. Brandon, S.M. Harasimowitz, P.N. Jones, B.J. Olson, M.L. Robinson, Groton, CT. Study for Naval Undersea Warfare Center, February, 1994.

17. Hughes, David, "NASA, USAF Pursue Phased Arrays", *Aviation Week & Space Technology*, Vol. 141, No. 11, pg.64-65, 12 September 1994.

18. MITRE Corporation, *Submarine Superhigh Frequency Satellite Communications Technology Second Interim Report*, by W.T. Brandon, S.M. Harasimowitz, P.N. Jones, B.J. Olson, M.L. Robinson, Groton, CT. Study for Naval Undersea Warfare Center, February, 1995.

19. Larson, W.J., and Wertz, J.R., *Space Mission Analysis and Design*, 2d ed, Microcosm, Inc., 1992.

20. Texas Instruments, Inc., *Advanced Technology Antenna Studies for the Advanced Technologies for Submarine Operations in the Littoral*, by Texas Instruments Incorporated, Defense Systems and Electronics Group, September 13, 1994.

21. Anselmo, J.C., and Biederman, A., *Commercial use seen for Milstar Antenna*, Aviation Week & Space Technology, Vol. 141, No. 3, pg.79, 18 July 1994.

22. Taira, S., Tanaka, M., and Shingo, O., "High Gain Airborne Antenna for Satellite Communication", *IEEE Transactions on Aerospace and Electronics Systems*, Vol. 27, No. 2, pg.354-360, March 1991.

23. The Armed Forces Communications and Electronic Association (AFCEA), *AFCEA Coursebook 102R: Military Satellite Communications*, March 1993.

24. Interview between Harry Hargrove, Geoffrey White, BOEING Defense & Space Group, Arlington, Va., 2 March 1995.

25. NISE East, *JMCIS Imagery Segments Training Guide*, St. Inigoes, MD., October 1994.

26. NISE East, *JMCIS Imagery: Architecture and Capabilities*, by Mark Kuzma, St. Inigoes, MD., April 1995.

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